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USE OF CELL AUTOPSY TO DIAGNOSE POTLINING PROBLEMS

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Abstract

The technique of cell autopsy, commonly used to determine the mode of failure of a single reduction cell, can be used to dig more deeply into potlining problems. Identification of such problems in a timely manner is important due to the long time horizon for implementation of the solutions. In this paper examples of problems with lining design, materials, cell construction, cell startup and cell operations found through the cell autopsy technique are described and illustrated.

Introduction

For many years, aluminum companies have employed post-mortem analysis of dead reduction cells (or cell autopsy) to determine the reasons they died [1, 2]. This technique is most often employed to investigate early failures, so its use in many plants is sporadic and often tends to look at the worst cases. This limits the usefulness of the technique because often there is no "normal case" with which to compare the results of an investigative autopsy. The use of the autopsy technique is most effective when it is employed regularly to go beyond the simple detection of failure modes to encompass the entire spectrum of cell lining problems.

A useful model for thinking about cell lining problems was popularized by Hale [3]. He proposed that there are five basic determinants of cell life which can be visualized as the pieces of a pie as in Figure 1.

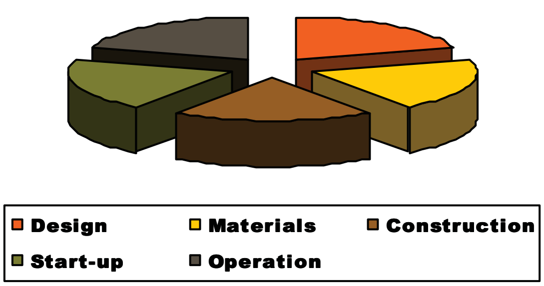

Figure 1. Determinants of Cell Life

The relative sizes of the pieces of the pie can be the subject of endless debate, but this goes beyond the classic case of the potroom manager blaming bad blocks for poor life and the block supplier pointing a finger at poor operating practices. It is an important role for technical management to understand the relative importance of each piece of the pie for the specific plant situation and direct the resources to work on the right problem. It does no good to change block suppliers if the relining crew does a sloppy job of ramming or if the thermal design is not suitable for the operating conditions. This is especially important given the cost of modern cell linings and the long time span of the relining cycle. Today's cells may cost $100-300,000 and are expected to live 5, 6 or even 10 years. The effect of a bad decision may not be seen for 2-4 years by which time hundreds of cells costing tens of millions of dollars could be affected. When we do cell autopsies we can look for and record many things other than the failure mode, and these findings are invaluable in pinpointing which of the five areas needs the most attention.

Cell Autopsy Process

In the autopsy process the cell must be dismantled in a controlled manner without water. There can be some variations depending on the tools and dismantling process at the plant, but generally the process is as follows:

1. Gather relevant data on cell construction, materials used, standard operational data, preheat and startup history and any special measurements taken such as ledge profiles or steel-shell temperatures.
2. If the cell is removed from the operating line for the autopsy, observe and record the condition of the stall from which it was removed,
3. Carefully remove the metal pad and all loose bath. Side ledge may be left on for observation. Vacuum the surface to reveal all the detail
4. Measure and record shell and deckplate deformation, and surface elevations. Record the location of all cracks, holes and other features.
5. Remove cathode blocks and underlying refractories and insulation to make a trench across the cell, revealing two cross sections. The number of blocks to be removed may be as few as 2 if the cell is to be restarted. Vacuum the surfaces to reveal the detail.
6. Measure and record all movements and transformations of material and record these on a drawing or scaled sketch of the lining. Photos are valuable, but cannot replace careful manual sketching. Samples can be taken to verify chemical composition or physical properties of the transformed materials.
7. Remove additional blocks or parts of blocks to investigate other areas of interest. In the most rigorous cases, each block is removed one by one. In many cases a cross section through the endwall is useful.
8. Assemble the information into a report with conclusions if possible. Sometimes the answer to a complex problem becomes evident only after several autopsies; therefore the most important aspect is proper preservation of the observational data.

Cell Design Issues

The design of the bus bars, steel shell and the lining itself are the first building blocks of long cell life.

Bus Bar Design and Magnetic Swirl

In older cells, generally running less than about 100kA, as well as the most modern magnetically compensated designs, the predominant surface erosion mode is the so-called "W" pattern where the cathode blocks are eroded near the ends where the current density is highest but left virtually unaffected in the center of the cell. In some end-riser cells, the W pattern is overshadowed by a very strong swirl at the upstream corners of the cell. This can be seen in the contour plot shown in Figure 2. In side-riser cells the most eroded areas are under the risers, but the pattern is not usually so strong.

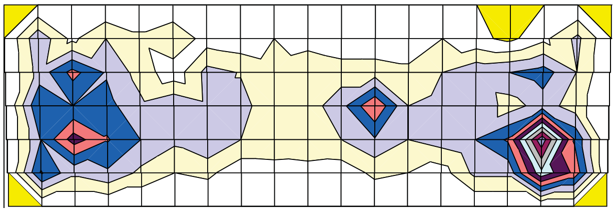

Figure 2. Typical surface contour, end-riser cell, 1600 days.

Lining Design Too Hot (Over Insulated)

If the lining design is over-insulated as in Figure 3, bath will penetrate into the insulation during operation. This destroys the insulating value and requires the use of extra energy to keep the cell warm and creates instability that may shorten its life.

In some cases, the design may have been right for the original operating conditions, but became over-insulated when amperage was increased. The autopsy work then becomes a major input for redesign of the lining.

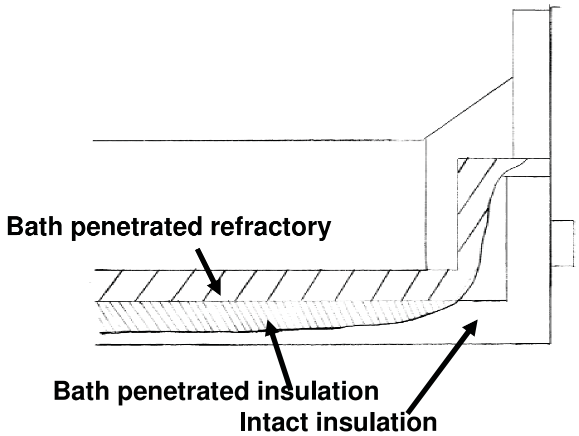

Figure 3: Over-insulated design. Insulation destroyed by normal bath penetration

Lining Design Too Cold (Under-Insulated)

If there is too little insulation, the cell will use excess energy but, worse, the cathode block will be cooler at the bottom than at the top. This promotes arching of the block and can eventually lead to upward heaving of the cathode panel and cracking of the blocks at or near the centerline of the cell. In Figure 4 we can see the under-insulated condition in the degree of bath penetration of the refractories in the lower sidewall pier.

Figure 4. Under-insulated design. Very little bath penetration of refractories as indicated by the arrow

Lining Materials

The quality of lining materials can often be seen directly, even when this is not the primary objective of the autopsy.

Cathode Blocks

The cathode blocks shown in Figure 5 were expanded by 20 cm. (70%) due to the horizontal cracking shown. This was traced to substitution of petcoke for a portion of the anthracite in the aggregate.

Figure 5: Severely delaminated cathode block, age: 180 days

Ramming Paste

Shrinkage of ramming paste, especially at the perimeter seam, can cause leakage of metal into the lining within hours of startup of the cell as shown by the arrow in Figure 6. In this cell metal not only leaked from the collector bar holes but ran beneath the cathode blocks and into the refractories.

Figure 6: Ramming paste shrinkage in perimeter seam. Age: 28 days.

Silicon Carbide Sidewalls

Figure 7 shows a side-by-side comparison of a proprietary bonding system for silicon carbide sidewall blocks with a standard nitride bonded block. The “proprietary” block on the left is already starting to oxidize at about 300 days.

Figure 7. Silicon carbide side-by-side test showing an inferior bonding system on the left

Cell Construction

The process of constructing the lining can introduce fatal flaws. The paste ramming process is particularly prone to error and variability, but other operations can also produce failure modes.

Paste Ramming

Areas of poor paste density or discontinuity between the paste layers, as seen in Figure 8, can be pathways for metal or bath penetration or develop into ratholes due to metal pad movement.

Figure 8: Rammed paste seam with poor bonding between layers seen within chalk marked area.

In Figure 9, we see a different problem where the paste layers did not bond properly due to over ramming and crushing of the aggregate particles. Metal eventually penetrated between the layers, leaving behind aluminum carbide.

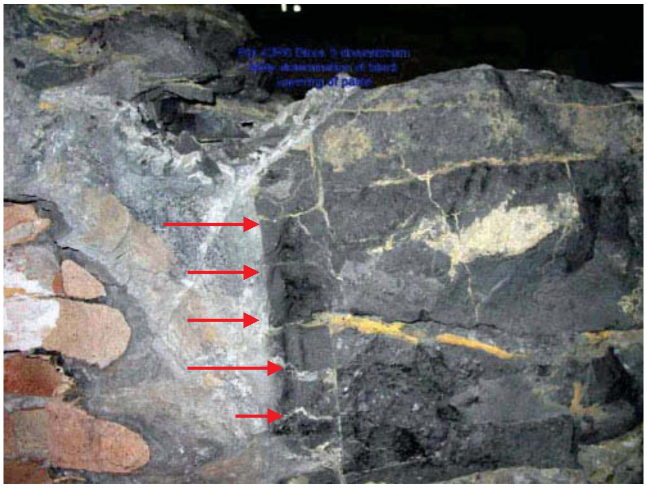

Figure 9. Aluminum carbide (indicated by arrows) in interfaces between paste layers, caused by over ramming.

<u>Collector Bar Casting</u>

In Figure 10 we see cracks running upward from the corners of the collector bar, sometimes called “wing cracks”. In the cell pictured, this was traced to inadequate preheating of the bar and block assembly during cast iron rodding of the bars.

Figure 10: Wing cracks (indicated by arrows) caused by collector bar casting

Cell Startup

<u>Cell Preheat</u>

The cell preheating process, which must be done in the “field” rather than in the regulated conditions of a furnace, can be very hard to control. The pattern, seen in Figure 11, of unconnected cracks running parallel to the length of the cell accompanied by holes and metal roots when the surface is flat is characteristic of hot spots created during electrical bake. Sometimes this is caused by resistor material with too large particle sizing.

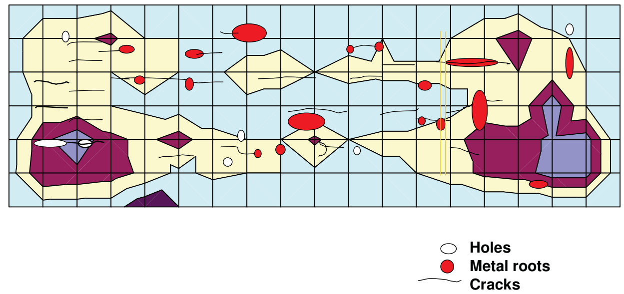

Figure 11: Surface features resulting from thermal shock during electrical bake, 450 days. Note that the contour pattern shown in Figure 2 is developing.

Figure 12 shows the interesting pattern seen when an electrically baked pot was stopped after 28 days. The resistor coke was laid in a pattern of narrow strips under the anode shadow. The eroded areas seen in the photo were up to 40 mm below the original surface, so before the cell was started it had already lost 15% of the thickness of the cathode blocks.

Figure 12: Surface of 28 day old pot baked with strips of coke

<u>Startup - End Block Cracking</u>

In Figure 13 we see a crack, across the center of the end cathode block and the initial development of a rathole from metal pad movement. Cells with high length to width ratio are especially susceptible to such cracking due to cumulative displacement during startup toward the ends of the cell that is not properly compensated by crushable materials.

Figure 13. Cracking of end cathode block.

Cell Operation

Finally, it is well known that poor operation is a sure pot killer. Erosion of sidewalls by failure to maintain proper ledge is a familiar scenario. Even nitride bonded silicon carbide does not last more than a few weeks and perhaps as little as a few days when exposed to liquid bath and metal. A few less common problems are illustrated below

Insulation of Shell Exterior

Material that is allowed to build up on the exterior of the shell will cause local overheating and distortion of the shell, eventually preventing ledge formation. Figure 14 shows an extreme example of this overheating caused by the entire trench between the cells being filled with ore and bath material. The resulting sidewall tapout is indicated by the arrow.

Figure 14: Sidewall failure due to full trenches

In Figure 15 we can see the overheating created when only the box created by the shell, cradles and collector bar strap was filled with ore and bath.

Figure 15: Shell distortion, shown by the arrow, from build up of material on the outside

Taphole Erosion

When the metal tapping equipment is not properly designed or the tapping process is not controlled, deep holes can be created by the vortex generated by metal entering the tapping tube. In many cases this has caused eventual failure of the cell. Figure 16 shows a contour plot of such a cell.

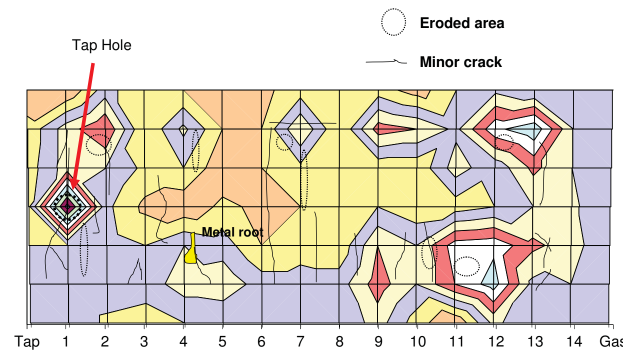

Figure 16: Surface contour illustrating taphole erosion. Age 2280

Reporting

The last step of the autopsy process which cannot be overemphasized is the preparation of the report. This should be in a format that is easily comparable to previous reporting. Since the time horizon for cell lining improvements stretches over years and sometimes even decades, proper historical record keeping is essential.

Results

Figure 17 shows the long term results of the consistent (and persistent) application of the technique of cell autopsy to diagnose the causes of cell failure coupled with the proper program to address the issues found in the autopsies. Only a few of the most significant developments are shown. The upper bound of life for the design in this plant was about 2000 days due to an active metal pad and thin cathode blocks. The trebling of potlife in a 20 year period was a significant cost saving factor.

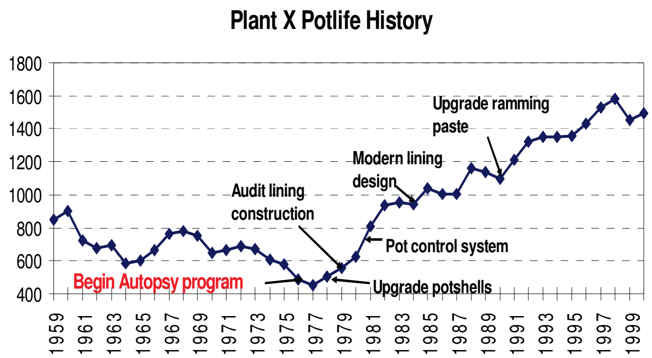

Figure 17: History of Potlife at Plant X

Conclusion

The technique of cell autopsy when applied on a regular schedule can be used to optimize the process of improving cell life. Such a regular autopsy program can go beyond the simple detection of failure modes to target improvement efforts toward the cell life determinants which will yield the most benefit for the resources expended.

References

1. Sorlie, M. and Øye, H, "Cathodes in Aluminium Electrolysis", 2nd Edition, Aluminium Verlag, 1994, pp 283-285.

2. McClung, M. and Zerkle, R., "Autopsy Procedures and Results at Century Aluminum of West Virginia", *Light Metals 2004*, p. 213-218.

3. Hale, W. "Improving the Useful Life of Aluminum Industry Cathodes", *Journal of Metals*, Nov. 1989, p. 20.