ON THE IMPORTANCE OF FIELD VALIDATION IN THE USE OF CELL THERMAL BALANCE MODELING TOOLS

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Plan of the Presentation

- **Introduction**
  - Cell development cycle
    1) Cell design through modeling
    2) Cell engineering and prototype cells construction
    3) Prototype cells operation
    4) Prototype cells measurement campaigns
    5) Prototype cells postmortem autopsy
    6) Model calibration and validation
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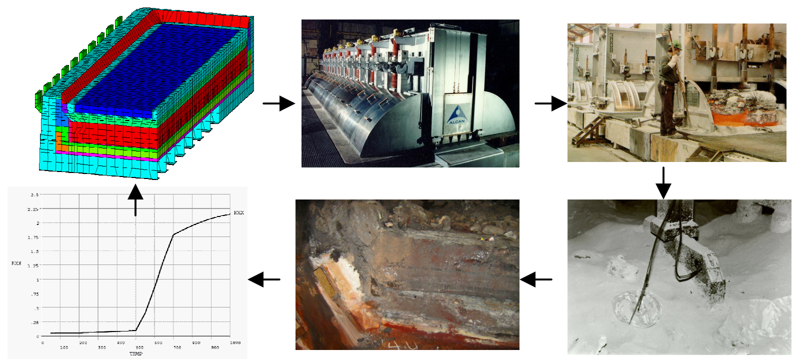
- **Prototype cells postmortem autopsy**
- **The over insulated cathode example**
- **The need for more field validation work**
- **Conclusions**

Introduction

To be successful, the design of high amperage cells must be conducted using the "cell development cycle" method

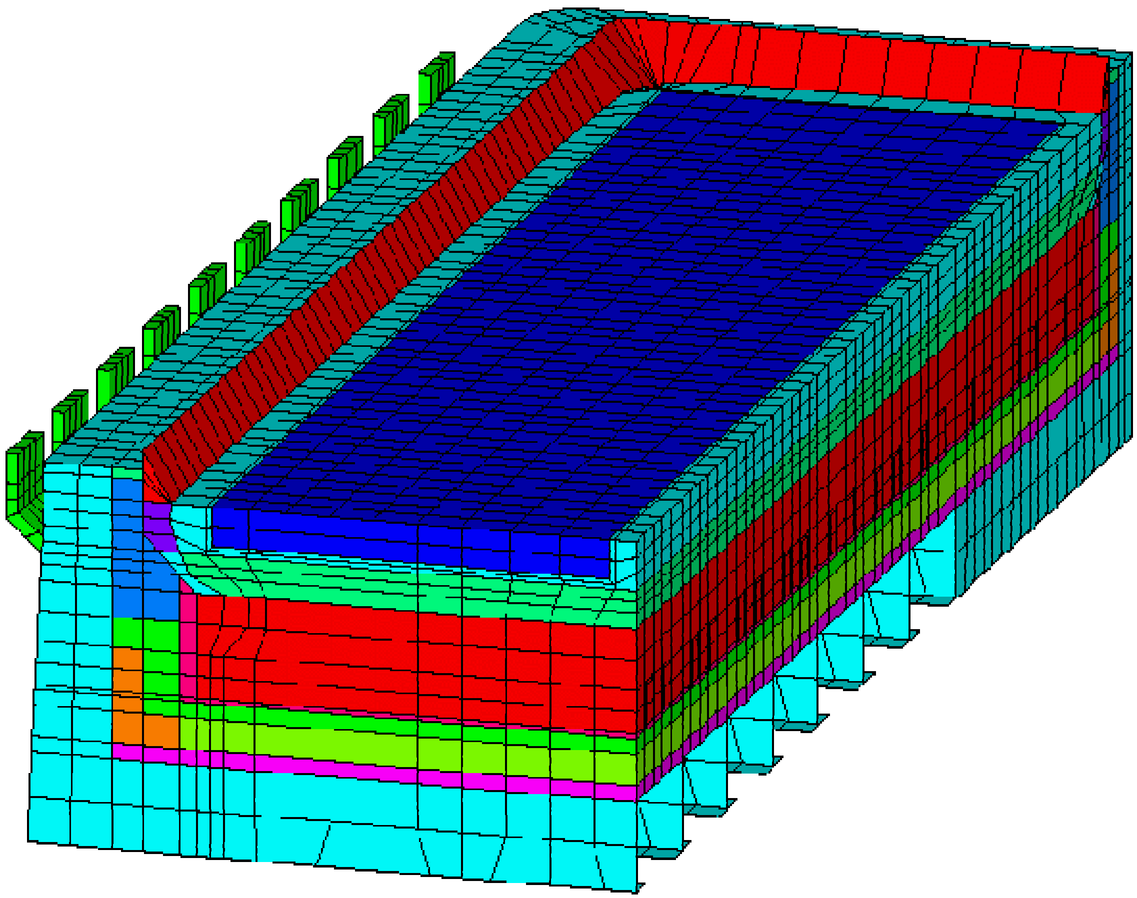
1) Cell design through modeling
2) Cell engineering and prototype cells construction
3) Prototype cells operation
4) Prototype cells measurement campaigns
5) Prototype cells postmortem autopsy
6) Model calibration and validation



Ref: V. Gaudreault, H. Vermette, V. Langlois and L. Lefrançois, "The Rio Tinto's P155 Smelters now Operating at 210 kA", COM Light Metals, 2011, 395-401.

Cell Design through Modeling

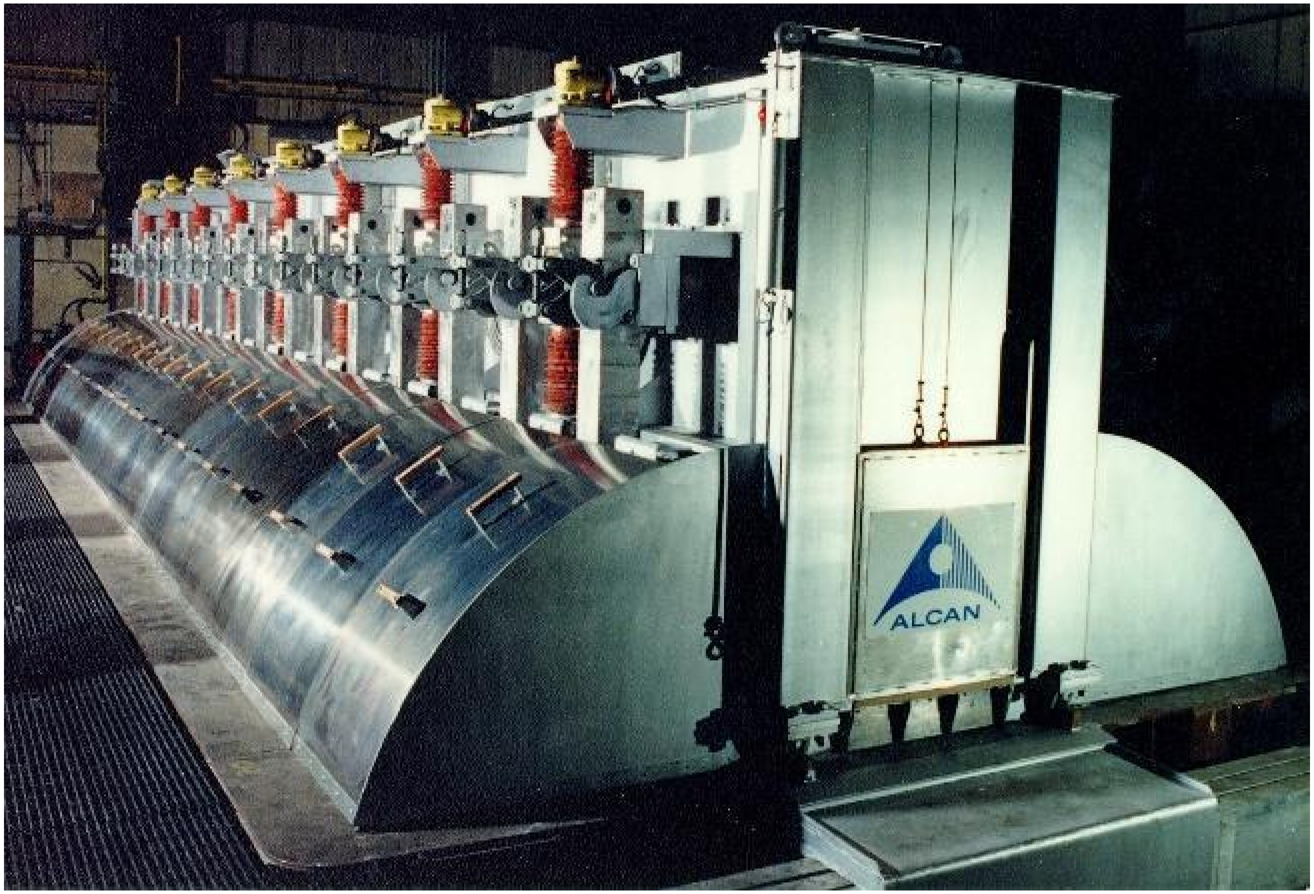
Models are indispensable in the process of designing modern, efficient high-amperage cells



Ref: M. Dupuis and I. Tabsh, "Thermo-electric analysis of aluminium reduction cells", Proceedings of the 31st annual conference of CIM, Light Metals section, 55-62, (1992)

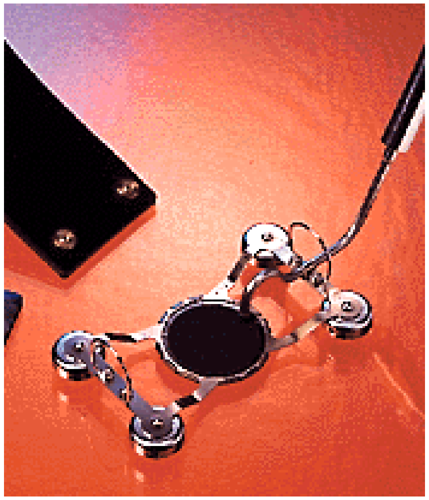
Cell Engineering and Prototype Cells Construction

Alcan A310 310 kA cell prototype 1989



Prototype Cells Heat Balance Measurement Campaigns

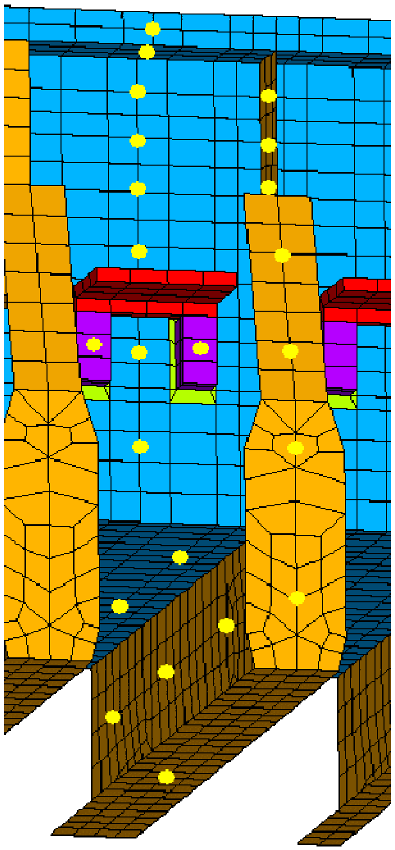
The first way to verify the accuracy of cell heat balance model predictions is to directly compare them with data obtained from prototype cell heat balance measurement campaigns



Measurement of the heat flux on the crust and the anode yoke using Japanese heat flux probes in the 70's

Prototype Cells Heat Balance Measurement Campaigns

This technique consists of measuring the heat flux at enough locations of the external surface of the cell to be able to calculate



Heat Balance Results

date:	5-Nov-03	Cell:	Cell 265	
Cathode Heat Losses		**W / m2**	**kW**	**%**
Shell side coverplate		821	2.26	2.00
Shell side spacer between boxes		1796	3.59	3.18
Shell side bottom box		3105	6.41	5.69
Collector bars to air		1337	7.96	7.06
Collector bars to flexible			2.40	2.13
Shell side wall collector bar level		625	0.57	0.50
Shell side wall insulation level		981	1.80	1.60
Shell side vertical boxes		918	1.97	1.75
Shell side floor perimeter section		1172	9.56	8.48
Shell side floor center section		1884	8.14	7.22
Shell end coverplate		809	2.21	1.96
Shell end spacer between boxes		1789	3.55	3.15
Shell end bottom box		3065	6.29	5.58
Shell end wall collector bar level		623	0.81	0.72
Shell end wall insulation level		969	1.82	1.61
Shell end vertical boxes		1150	2.16	1.92
Shell end floor perimeter section		1165	6.34	5.62
Total for the cathode part			**67.82**	**60.17**
Anode Heat Losses				
Crust		306	2.85	2.53
First side channel		4002	12.11	10.74
Second side channel		2037	6.16	5.47
Third side channel		1206	3.65	3.24
Forth side channel		739	2.24	1.98
Above forth side channel		554	1.70	1.51
Anode top		552	4.13	3.67
Studs			12.06	10.70
Total for the anode part			**44.9**	**39.83**
Total for the cell			**112.7**	**100.00**
Cell internal heat			**117.8**	
Blitz closing			**95.71%**	

Ref: M. Dupuis, A. Koshie, V. Janakiraman, S. Karthikeyan and D. Saravanan, "Accurate Assessment of the Hirakud Smelter Aluminium Reduction Cell Thermal Balance using only Temperature Measurements", COM Light Metals, 2004, 525-533.

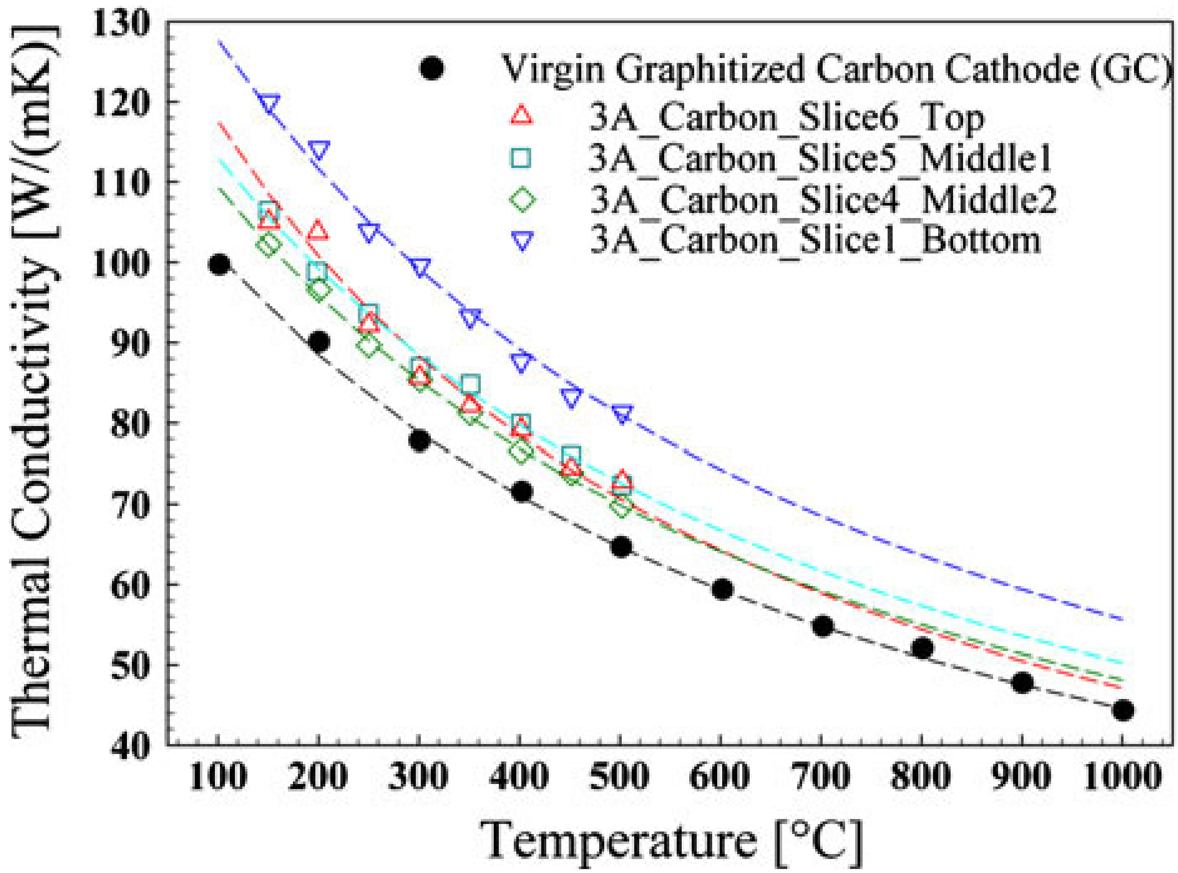
Prototype Cells Postmortem Autopsy

It is not uncommon to stop some prototype cells for the purpose of obtaining visual informations about the lining conditions

Ref: C. Schøning, A. Solheim and E. Skybakmoen. Deterioration of the Bottom Lining in Aluminium Reduction Cells, Part II: Laboratory Data and Autopsies. Paper presented at the Aluminium of Siberia 2008, XIV International Conference:76–82, 2008.

Prototype Cells Postmortem Autopsy

It is also not uncommon to stop some prototype cells for the purpose of obtaining the type of data presented in the graph below



Ref: K. Tschöpe, C. Schøning, J. Rutlin and T. Grande, "Chemical Degradation of Cathode Lining in Hall-Héroult Cells – An Autopsy Study of Three Spend Pot Linings", Metallurgical and Materials Transactions B, Vol 43B 2012, 290-301.

The Over-insulated Cathode Example

Cell development cycle

1) Cell design through modeling
2) Cell engineering and prototype cells construction
3) Prototype cells operation
4) Prototype cells measurement campaigns
5) Prototype cells postmortem autopsy
6) Model calibration and validation

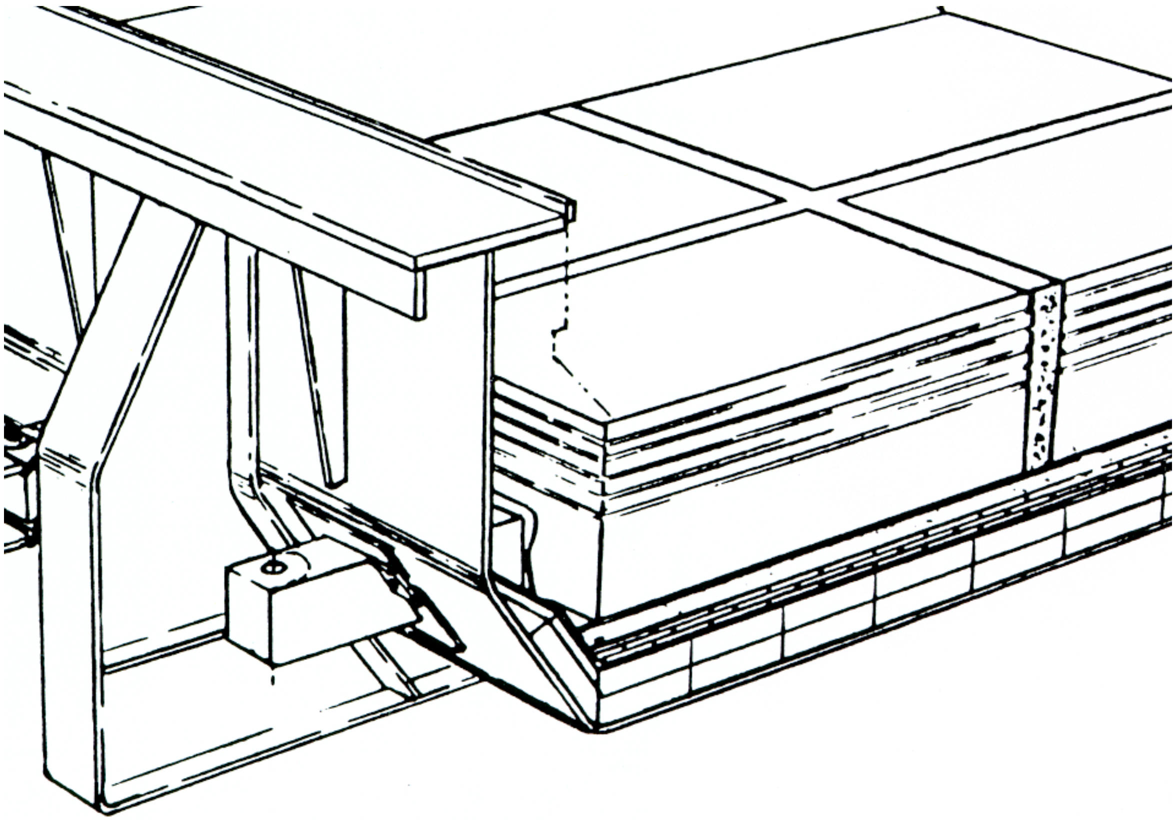
Hall-Héroult cells are very challenging to model.

Many of the inputs to a thermal balance model are difficult to evaluate, a process for validation of the predictions of the model is essential.

A practical example is presented here in detail in order to clearly highlight the consequences of using an unvalidated cell heat balance model to come up with a cathode lining design.

The Over-insulated Cathode Example

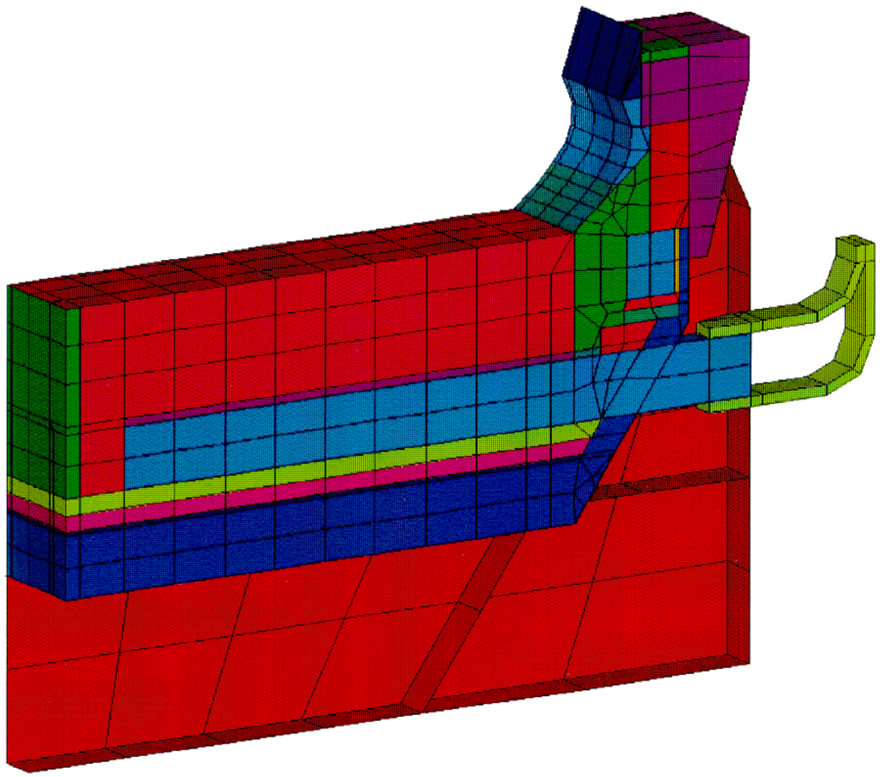
This practical example is quite well covered in the literature. It is the case of the over insulated Alcoa P155 cathode lining. Notice that the original Alcoa A697 lining design is essentially the same.



Ref: Marc Dupuis and Imad Tabsh, "Thermo-Electric Analysis of the Grande-Baie Aluminium Reduction Cell", TMS Light Metals, 1994, 339-342.

The Over-insulated Cathode Example

In the quoted reference, several types of cathode models were presented; the figure below shows the cathode side slice model. The navy blue material above the potshell floor is the calcium silicate.



Ref: Marc Dupuis and Imad Tabsh, "Thermo-Electric Analysis of the Grande-Baie Aluminium Reduction Cell", TMS Light Metals, 1994, 339-342.

The Over-insulated Cathode Example

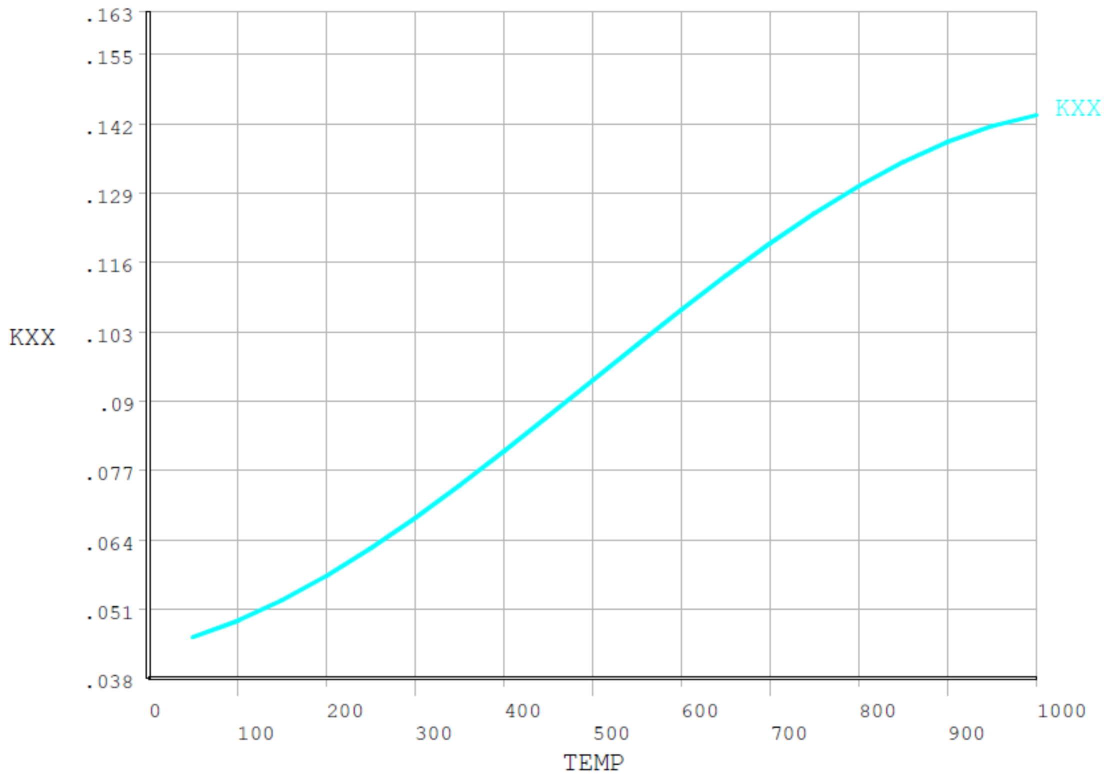
Model Calibration

- Model calibration is the critical phase of any development, and the Grande-Baie model is no exception.
- The initial results presented here,
- ~ 215 kW of cathode heat loss and ~ 350 mV of lining drop, do not compare well with the experimental results obtained from thermo-electric "blitz" campaigns,
- ~ 250 kW of cathode heat loss and ~ 320 mV of lining drop.

Ref: Marc Dupuis and Imad Tabsh, "Thermo-Electric Analysis of the Grande-Baie Aluminium Reduction Cell", TMS Light Metals, 1994, 339-342.

The Over-insulated Cathode Example

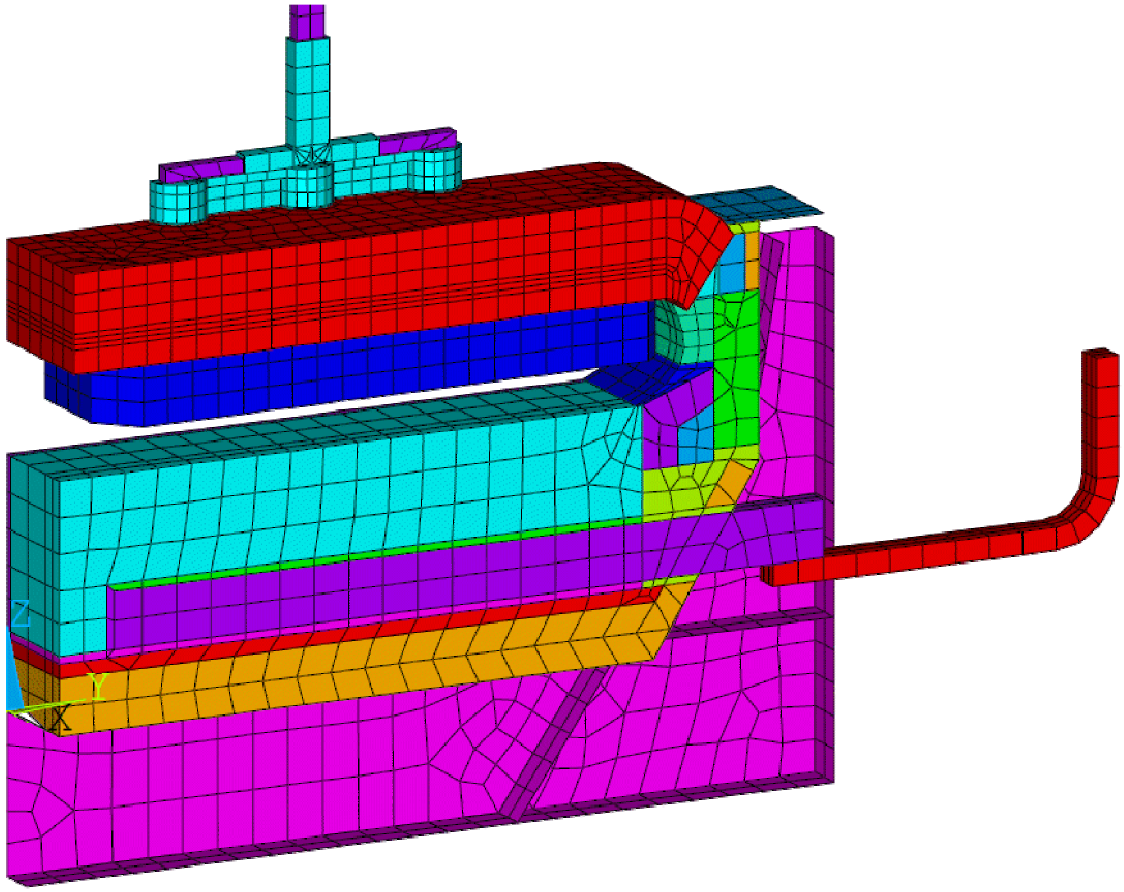
Calcium silicate is a fairly good thermal insulator; the typical temperature dependent thermal conductivity of that material is presented in the figure below



Temperature dependent thermal conductivity of new calcium silicate material

The Over-insulated Cathode Example

In the current study, a similar A697 full cell slice model was run first using the new calcium silicate temperature dependent thermal conductivity presented in the previous slide.

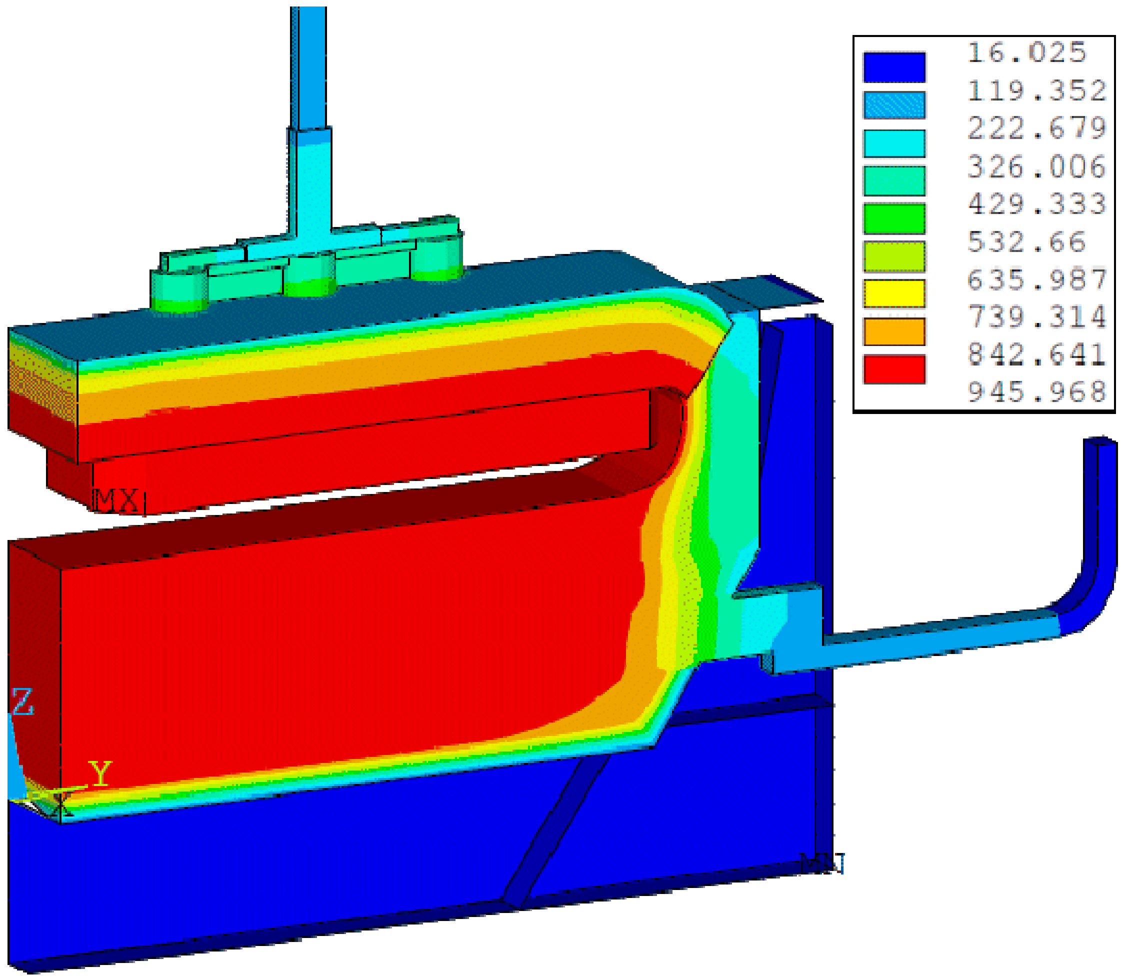


A697 full cell slice model mesh used in this study

The Over-insulated Cathode Example

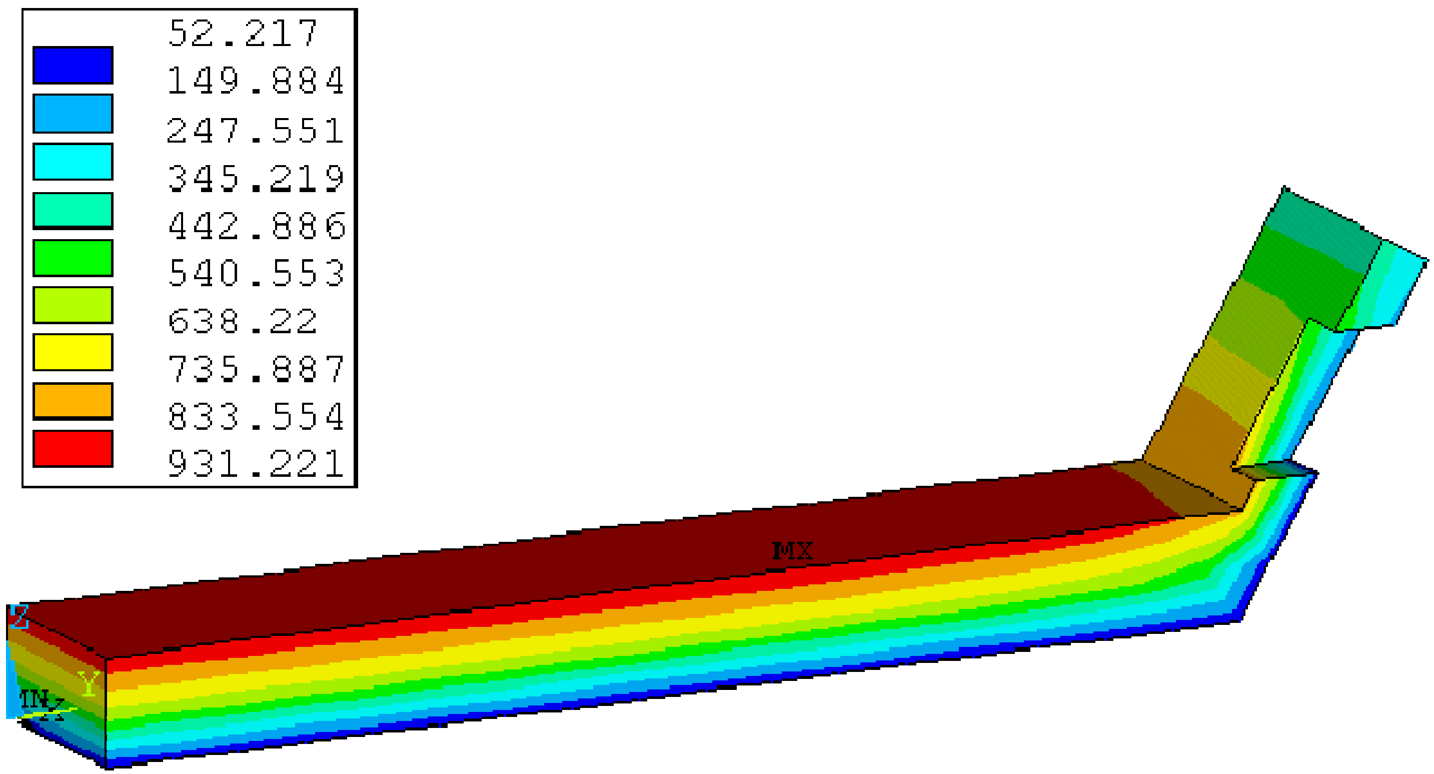
The obtained temperature solution is presented in the figure below

A697 full cell slice model temperature solution using new calcium silicate property



The Over-insulated Cathode Example

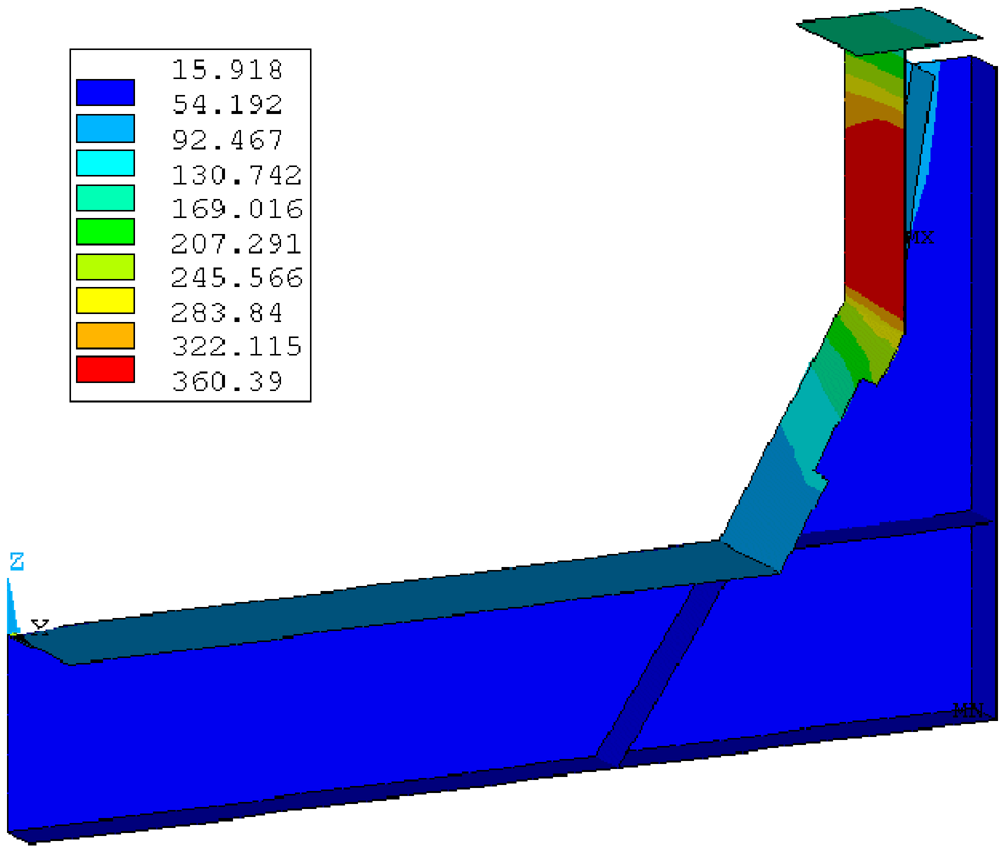
The temperature solution of only the calcium silicate material is presented in the figure below, we can see that the top section is reaching above 900 ℃



Calcium silicate temperature solution using new calcium silicate property

The Over-insulated Cathode Example

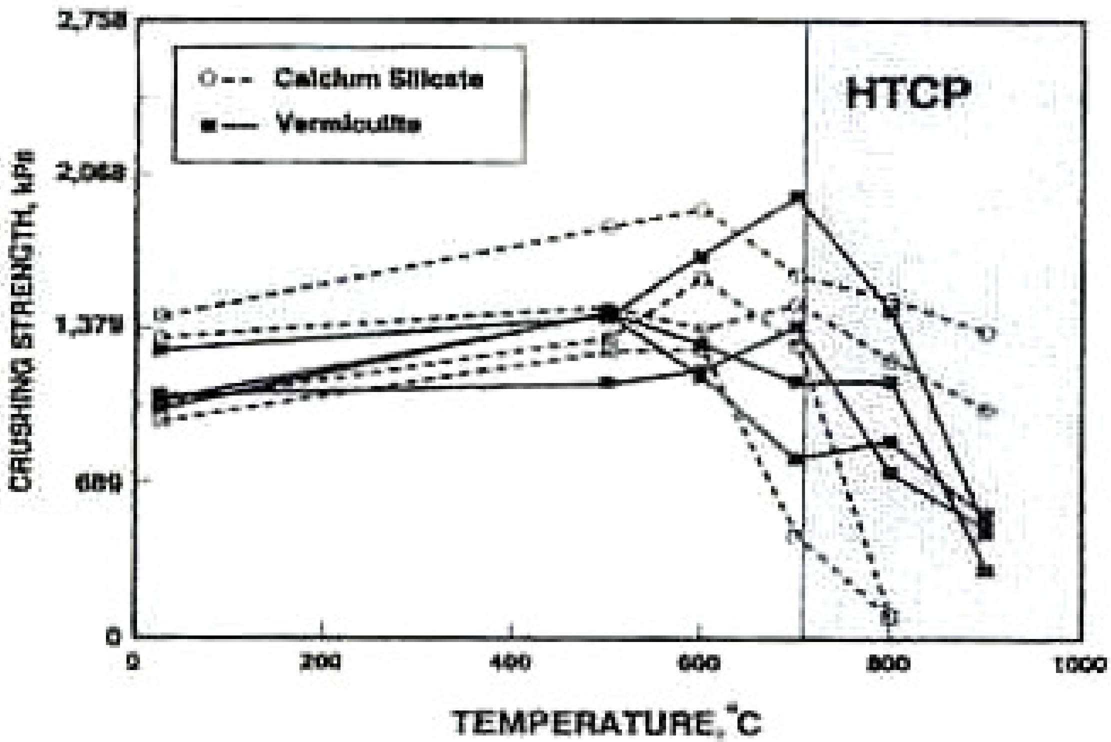
The cathode bottom heat loss is quite easy to observe as it significantly affects the potshell floor temperature



Potshell temperature solution using the new calcium silicate property

The Over-insulated Cathode Example

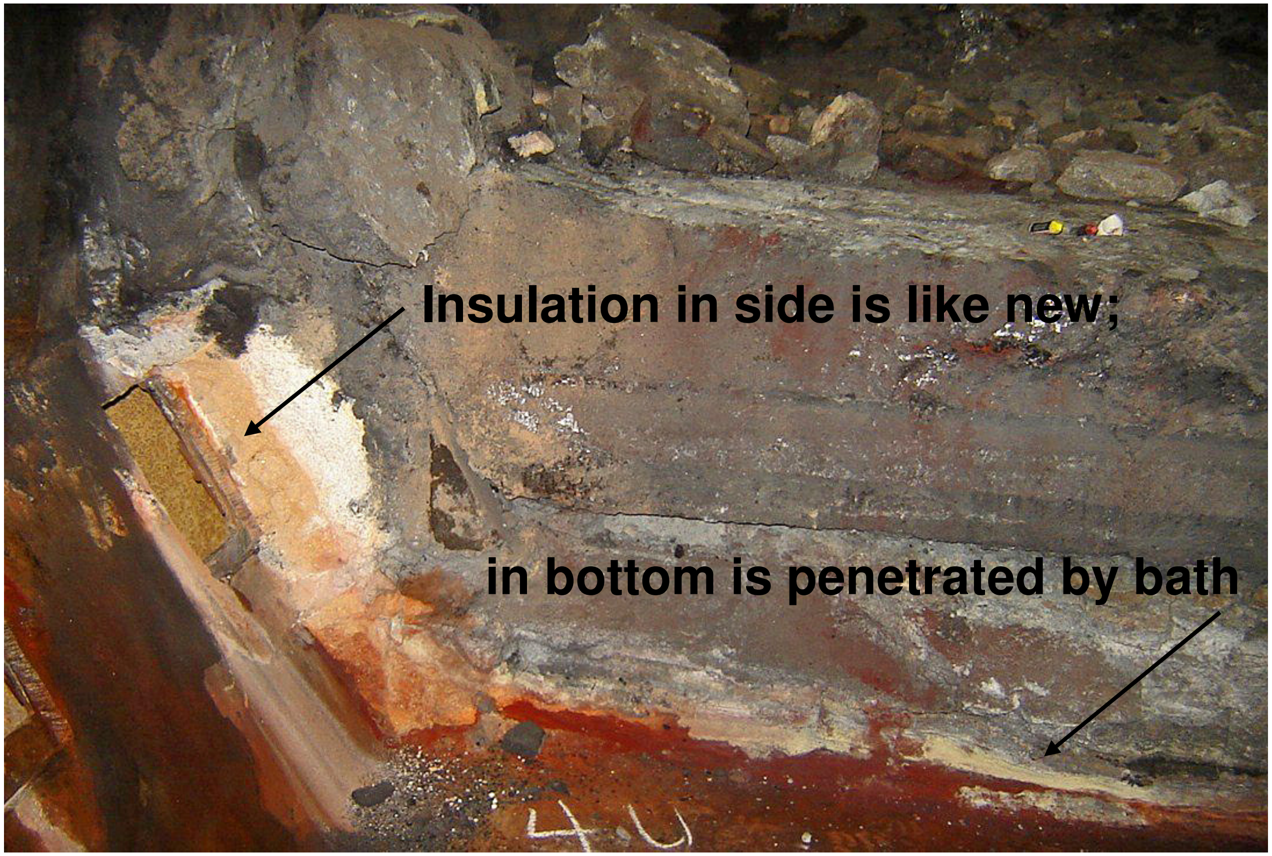
Light insulating materials are exposed to degradation both by high temperatures and by reaction with bath chemicals. It has been shown that above about 700 °C, these materials will lose much of their insulating property



Ref: A. T. Tabereaux and D. V. Stewart, "High-Temperature Critical Point (HTCP) for Insulating Blocks Used for Cathode Insulation", COM Light Metals, 1992, 103-114.

The Over-insulated Cathode Example

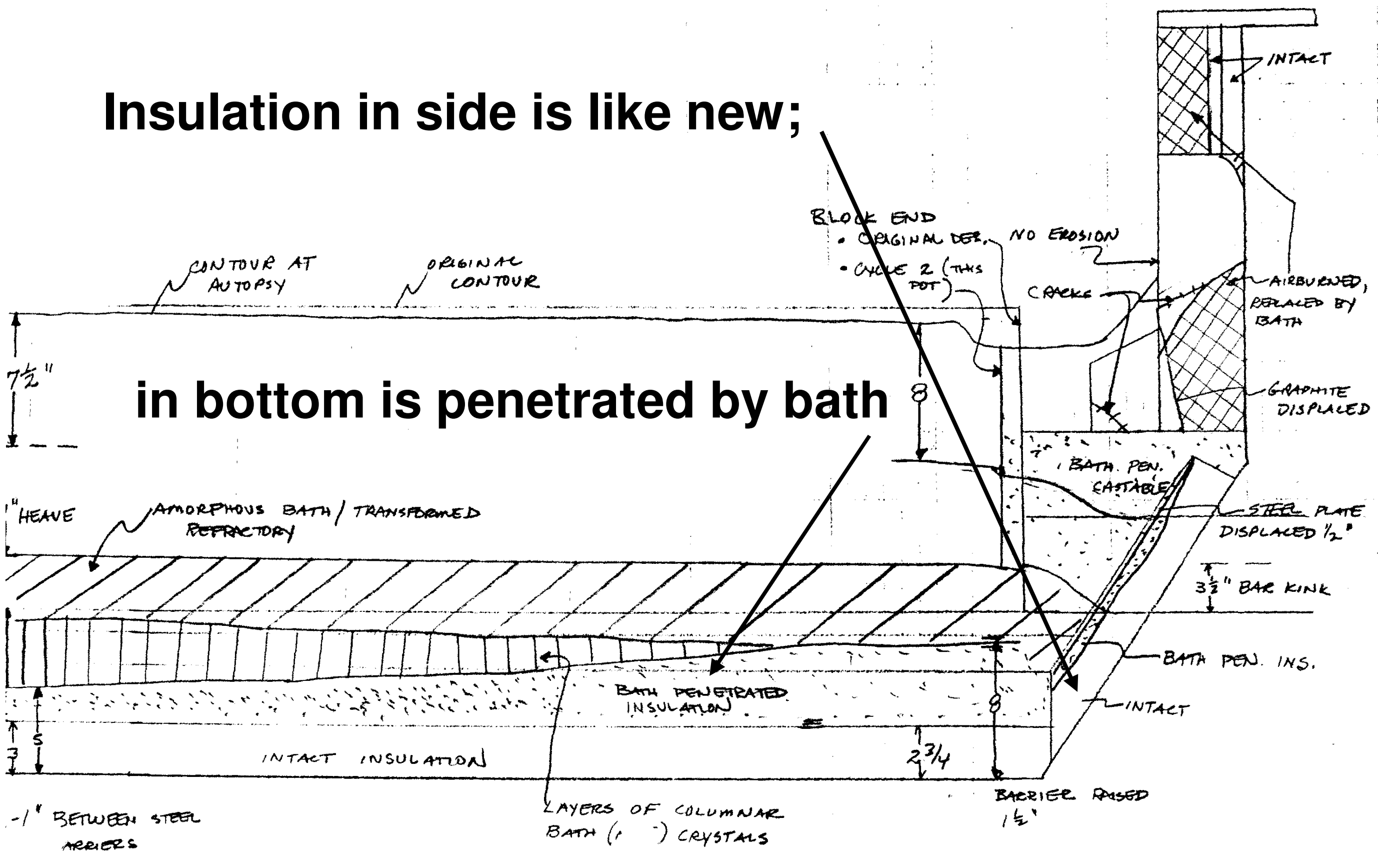
Autopsy results confirm the chemical degradation of very large portion of the thick insulation layer as presented in the figure below



Ref: Richard Jeltsch, "Use of Cell Autopsy to Diagnose Potlining Problems", TMS Light Metals, 2009, 1079-1084.

The Over-insulated Cathode Example

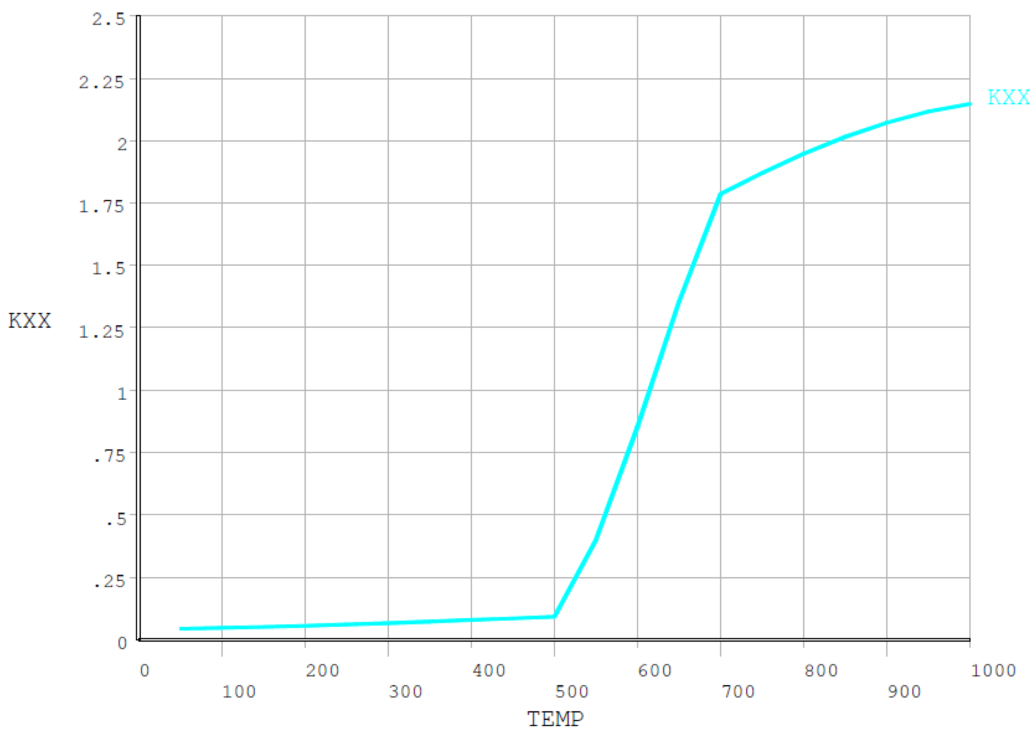
Autopsy results confirm the chemical degradation of very large portion of the thick insulation layer as presented in the sketch below



Ref: Richard Jeltsch, "Use of Cell Autopsy to Diagnose Potlining Problems", TMS Light Metals, 2009, 1079-1084.

The Over-insulated Cathode Example

In order for the model to take into account that chemical degradation that occurs in the calcium silicate exposed at high temperature, the temperature dependent thermal conductivity needs to be adjusted as presented in the figure below

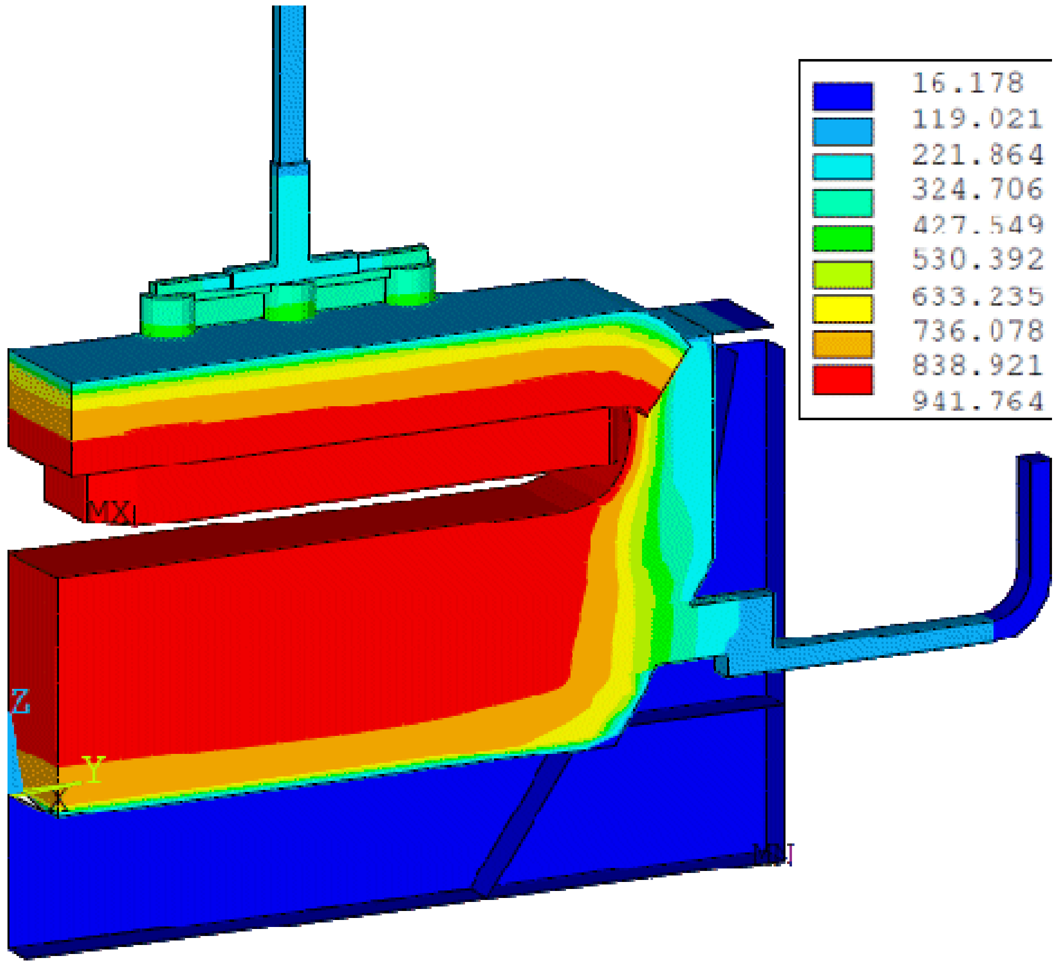


Temperature dependent thermal conductivity of calcium silicate material used in cell lining

The Over-insulated Cathode Example

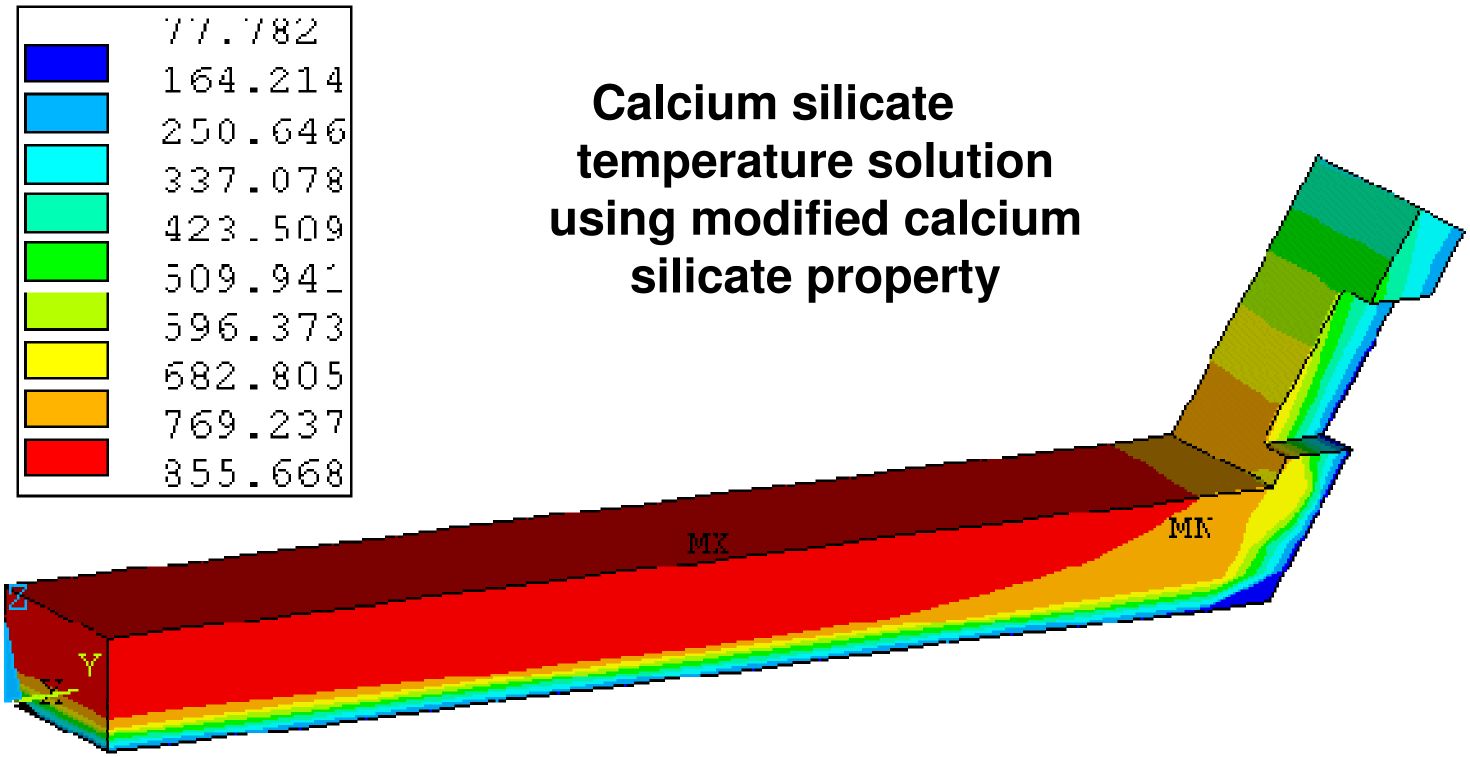
The obtained modified temperature solution is presented in the figure below

A697 full cell slice model temperature solution using modified calcium silicate property



The Over-insulated Cathode Example

The temperature solution of only the calcium silicate material is presented in the figure below, we can see that the top section has lost its insulating property

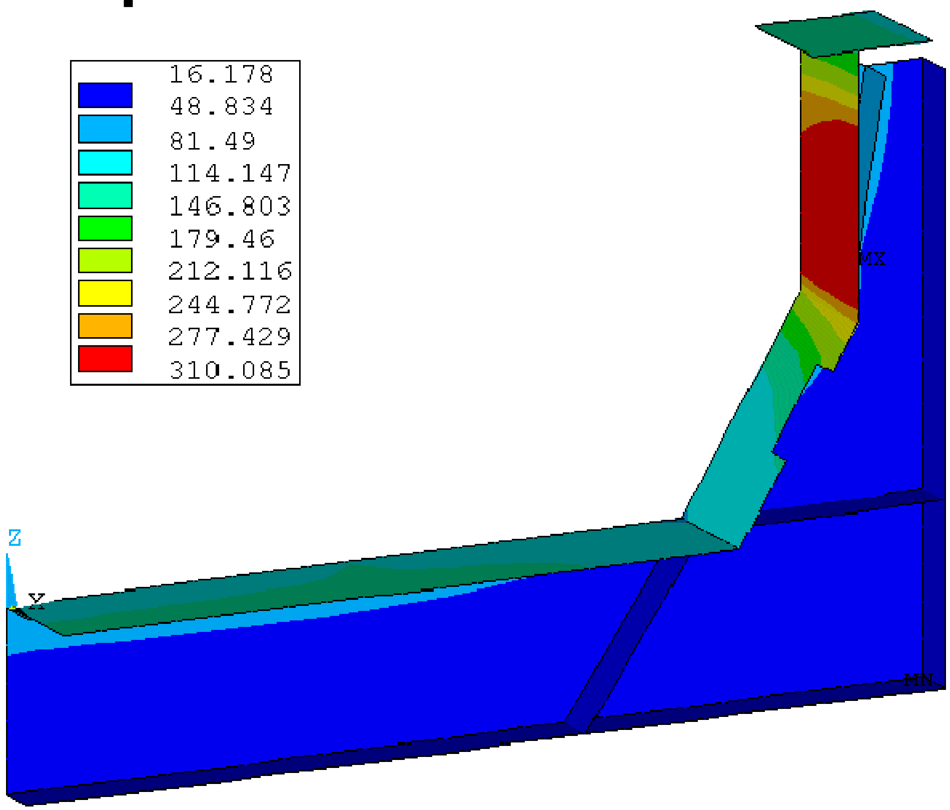


Calcium silicate temperature solution using modified calcium silicate property

The Over-insulated Cathode Example

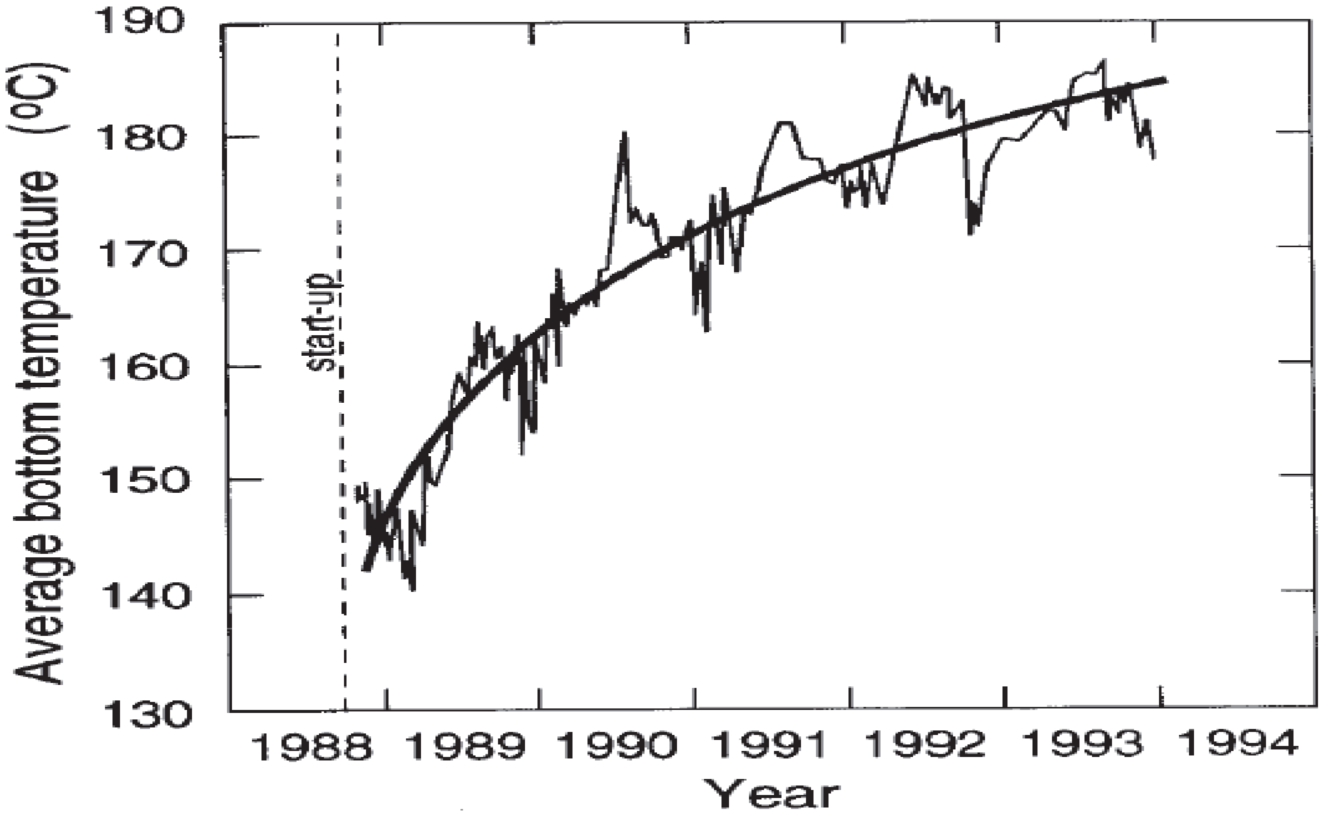
Since the cell internal heat was kept the same, the converged cell heat loss remained the same but the heat loss partition is now very different: the cell bottom floor dissipates more heat while the cell side wall now dissipates less heat

Potshell temperature solution using the modified calcium silicate property



The Over-insulated Cathode Example

That type change of the potshell floor temperature have been measured and reported for a 155 kA cell, those measurements are presented in the figure



Ref: Morten Sørlie, Hermann Gran and Harald Øye, "Property Changes of Cathode Lining Materials during Cell Operation", TMS Light Metals, 1995, 936-945.

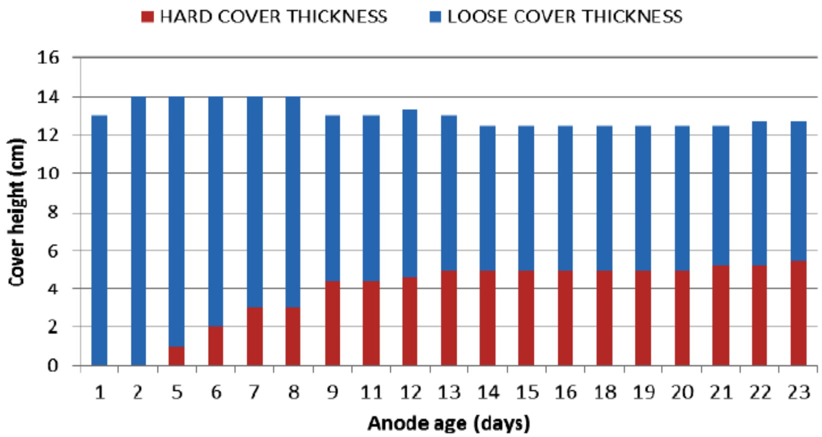
The Need for More Field Validation Work

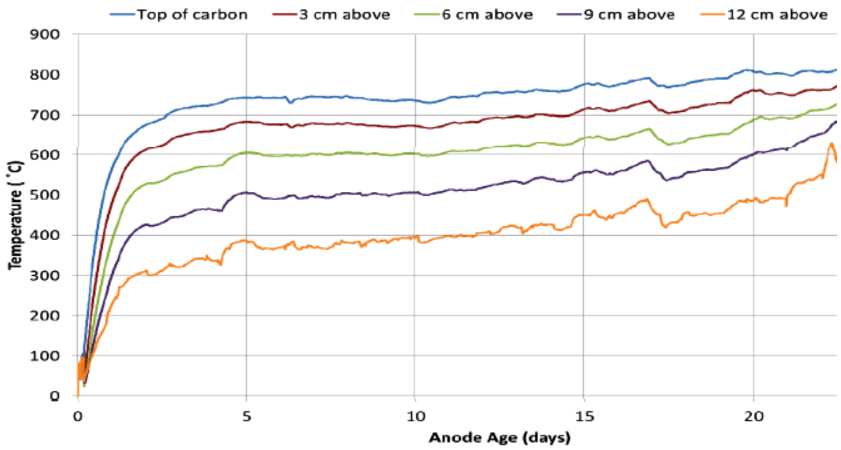
The story of the over insulated cathode lining with a too thick layer thickness of calcium silicate that could not possibly avoid chemical degradation regardless of the type of physical barrier put in place to try to protect it is quite instructive as it is not unique.

Calcium silicate is not the only material that is susceptible to chemical attack and significant properties changes when put in cell operating conditions.

The Need for More Field Validation Work

Anode cover material is another example of equal importance that also has been the object of significant studies over the years including quite recently.





Ref: Amal Aljasmi, Alexander Arkhipov and Abdalla Al Zarooni, "Evaluation of Anode Cover Heat Loss", ICSOBA, 2015.

The need for more field validation work

On the other hand some material would need more characterization work, for example the dry barrier material extensively used in Chinese lining designs. Despite the recent work done, there is certainly a need for more work in order to come up with a validated temperature dependent thermal conductivity property to be used in cell thermal balance modeling.

Ref: Richard Jeltsch, Liu Ming, Zhou Dongfang and Liu Wei, “Pot Autopsy and Material Selection in Cathode Linings”, Chinese Light Metals, 2015.

The need for more field validation work

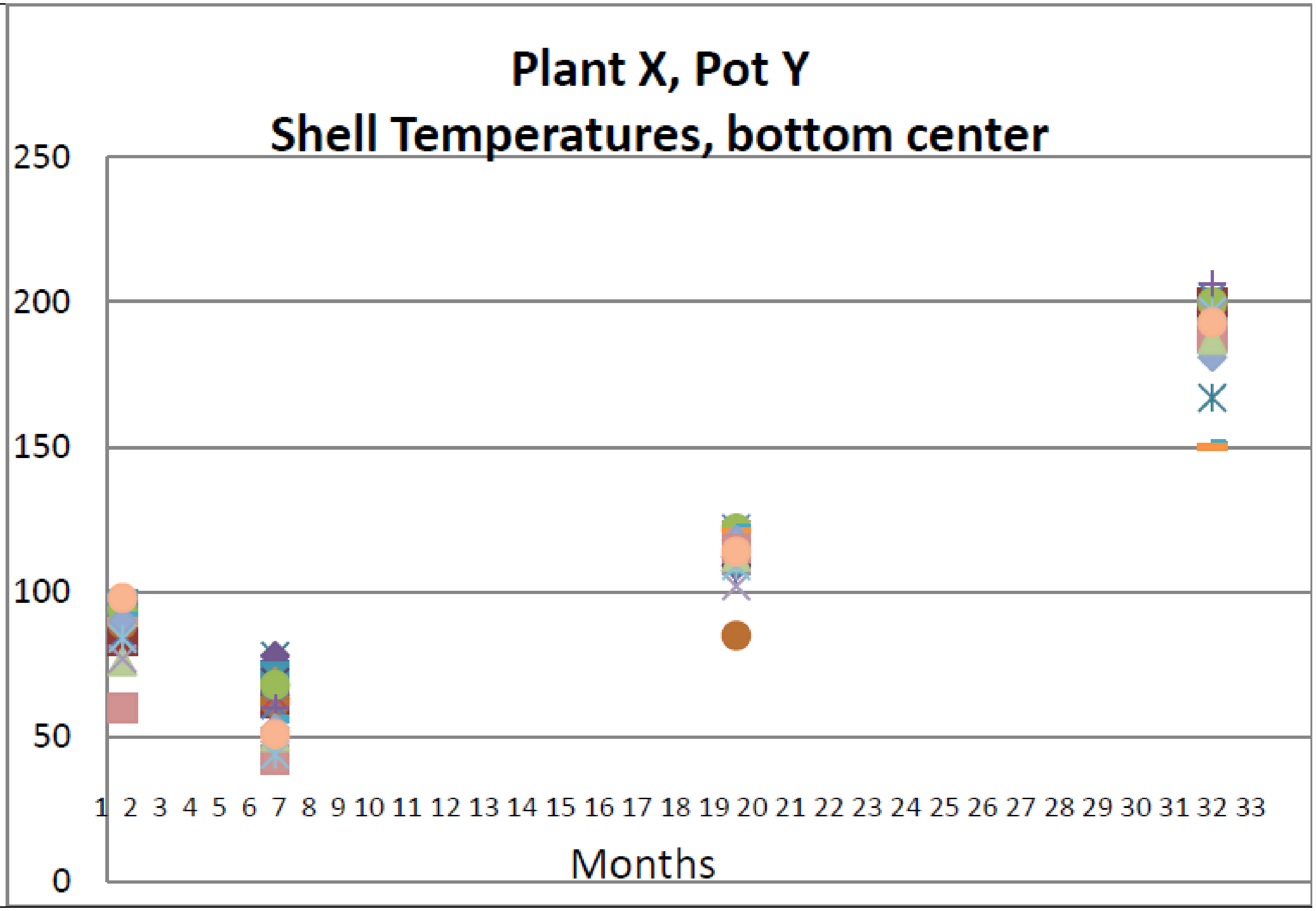


Fig. 8 Bottom shell temperatures for pot pictured in Fig 7

Ref: Richard Jeltsch, Liu Ming, Zhou Dongfang and Liu Wei, "Pot Autopsy and Material Selection in Cathode Linings", Chinese Light Metals, 2015.

Conclusions

- In order to be successful, the cell design of high amperage cells must be conducted using the "cell development cycle" method. The method comprises several steps, from modeling to measurement campaigns that must be used in repetitive cell design improvement cycles:

    1) Cell design through modeling
    2) Cell engineering and prototype cell construction
    3) Prototype cells operation
    4) Prototype cells measurement campaigns
    5) Prototype cells postmortem autopsy
    6) Model calibration and validation

Conclusions

- Only data obtained from cell prototypes in steps 4 and 5 of the cell development cycle can be used in order to get reliable predictions from cell thermal balance models.
- The first way to verify the accuracy of a cell heat balance model predictions is to directly compare them with data obtained from prototype cell heat balance measurement campaigns.

Conclusions

- The only way to directly obtain the used material properties required as inputs in models is to stop the prototype cells, dig out samples and measure the properties of those samples at a range of operating temperature.
- For example, it is well known that above about 700 ℃, light insulating materials such as calcium silicate will get exposed to chemical degradation and will lose much of their insulating property.

Conclusions

- In order for the model to take into account the chemical degradation that occurs in the insulation exposed at high temperature, the temperature dependent thermal conductivity needs to be adjusted.
- The thermal conductivity of other materials such as the dry barrier material used in Chinese lining designs also must be characterized after exposure to high temperatures and penetration by cathodic bath materials.