AL03 - A Modernized ANSYS-Based Finite Element Model for the Thermal-Electrical Design of Aluminum Reduction Cells

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Abstract

Heat balance and magnetohydrodynamics are critical to the design of an aluminum reduction cell since they largely determine its operational window. Furthermore, an inadequate lining design generally leads to degraded cell performance and premature failures. The first task in lining design is to determine the position of the frozen ledge and the cell superheat for a range of operational parameters.

Although several different modeling approaches and computational domains have been proposed to solve the Stefan problem, a widely accepted methodology, first proposed by Dupuis [1], is based on the iterative repositioning of the ledge front in a thermoelectrical (TE) Finite Element (FE) model. The algorithm involves successive displacements of the solidification front nodes based on the calculated temperature field until the entire ledge-to-liquids interface reaches the bath solidification temperature. The superheat is adjusted to minimize the difference between the cell internal heat generation and the integrated heat losses over the control volume. Originally, this approach was limited to two layers of first order elements across the ledge thickness moving horizontally and did not include the liquids.

This paper presents a generalization as well as improvements to the original methodology, enabling the prediction of the ledge profile using an arbitrary number of first or second order elements through the ledge thickness while including the metal pad and the bath. The proposed modeling framework has been implemented in ANSYS using the ANSYS Parametric Design Language (APDL) scripting language and designed to minimize the computational cost of moving the ledge. Another benefit is that the generic core macros developed also efficiently handle the ledge front displacement in any orientation. Current technology ANSYS elements are used, in such a manner that high-performance computing solvers can be leveraged.

The robustness of this improved methodology is illustrated in this article by comparing the results obtained for a fictitious 300 kA cell technology against those computed by the standard approach.

Keywords: Aluminum reduction cells, heat balance, moving ledge profile, finite element analysis.

1. Introduction

Hatch has long been involved in the assessment of aluminium reduction technologies for greenfield and brownfield smelter projects and has recently been mandated to evaluate designs for a brownfield retrofit project, and specifically to perform heat balance calculations. Numerical modeling is considered the best tool to study the thermal-electrical behavior of the lining and the methodology is mature and widely accepted.

An essential part of the modelling effort is to predict the ledge profile, which can be quite challenging. Dupuis first developed a FORTRAN routine to reposition the ledge of a cathode slice and solved the TE problem by means of a finite element analysis in the commercial software ANSYS. The approach was then implemented in the ANSYS interpreted scripting language APDL [1]. The model domain was progressively enlarged to include a full quarter cell [2] but did not include the liquid phases at this point. The electrical boundary conditions were applied to the immerged surface of the anodes and to the top surface of the cathode blocks as an electrical equipotential.

Dupuis introduced a full cell slice (*i.e.* including both anode and cathode segments) with combined convergence of cell superheat and the ledge profile in [3]. The liquid zone for the full quarter was later introduced in [4] thus allowing one to obtain a representative current distribution in the metal pad.

The same modeling approach to move the ledge continued to be employed by Dupuis from the mid-1980's up to his most recent work in 2019 [5]. During that period, the ANSYS software platform has evolved, such that some of the functionalities used by Dupuis became no longer entirely compatible with the most recent versions of said software package.

Furthermore, the Authors agree that some of the drawbacks of the original Dupuis approach are the following:

The construction of the geometry is from the bottom-up and requires experience with ANSYS APDL

The discretization of the domain is limited to linear elements

In particular, the discretization of the ledge thickness is limited to 2 elements

The ledge mesh is attached to the cathode surface, which is limiting for the construction of the corner geometry. It also limits the position of the ledge toe as it depends on the cathode block assembly topology

The processing time for moving ledge and update boundary conditions is substantial

The models are based on legacy ANSYS elements

- These elements do not support present-day Distributed Memory Parallel (DMP) processing, which substantially increases computational performance of large models
- Furthermore, thermal loads are, in some instances, applied directly to the faces of solid elements, which is no longer supported by some of the current-technology ones (e.g., SOLID231).

From all of the above, it became quite clear that the original Dupuis approach could be improved in order to obtain a modernized methodology that is fully compatible with ANSYS 2020 R1. This was accomplished by rewriting critical routines and restructuring the modeling workflow.

2. Modernized Approach Workflow

The new workflow is summarized in Figure 1.

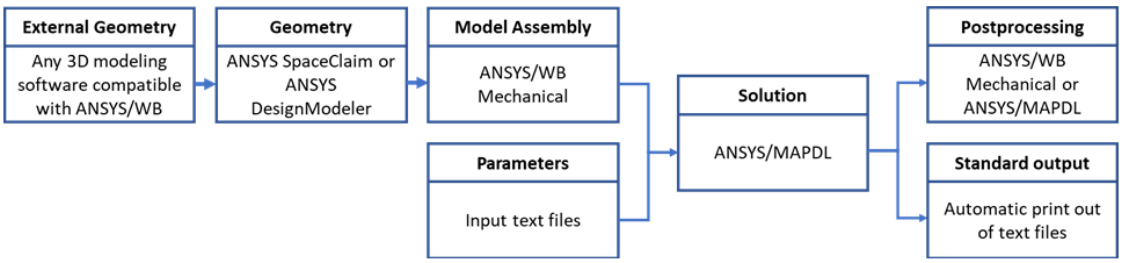

Figure 1. Modernized approach workflow.

7. Conclusions

A modernized approach to thermal-electrical finite element modeling of the cell heat balance problem has been developed in the commercial software package ANSYS 2020 R1. The new workflow is based on a combination of an interactive ANSYS/Workbench session, User-edited input text files, and generic APDL scripts running in the background. The main limitations of the original approach were eliminated and the use of the most recent ANSYS element technology enables leveraging the high-performance parallel computing solvers, including the sparse Distributed Domain Solver (DDS).

The modernized model was compared to the original approach for a complete quarter cell heat balance and ledge profile solution and results were found to be very similar. Convergence of the ledge profile was obtained for a linear and a quadratic mesh with (virtually) identical results.

A novel ledge topology was developed based on the displacement of the ledge nodes orthogonally to any arbitrary set of planes. The new topology allows the computation of otherwise impossible to converge problems.

Further work includes experimental validation of the heat balance model and assessment of the ability of the novel ledge topology to accurately predict the position of the ledge toe.

8. Acknowledgements

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9. References

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