ANSYS in the aluminum industry

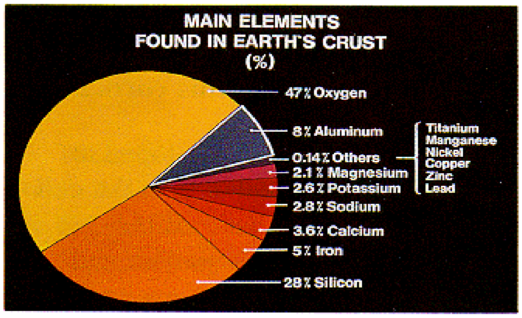

Figure 7. At 8%, aluminum is the most abundant metal of the earth.

Aluminum is the most abundant metal of the earth. It makes up about 8% of the earth's crust (Figure 7), third to oxygen and silicon. It weighs far less than other metal materials, resists corrosion, conducts heat and electricity, reflects light, and is non-magnetic. For over 20 years, major aluminum companies have used programs such as ANSYS to analyze and test their products. Aluminum is used in many different industries including aerospace, transportation, automotive, some electronics, and in many consumer products such as aluminum cans and baseball bats. The ANSYS program has many features developed or related to aluminum such as electric resistance heating, thermal-flow coupling, and magnetic capabilities.

Analysis of aluminum reduction cells

Alcan International, Ltd., is one of the world leaders in the production of aluminum and manufacturing of aluminum products. The company has been using the ANSYS program at its three research laboratories for over a decade. In particular, the Arvida Research and Development Center (ARDC) in Jonquière, Quebec, (Canada) has used the program extensively for the design of aluminum reduction cells with the help of CompuSim, Inc., an engineering consulting firm in Calgary, Alberta, and H.G. Engineering, the ANSYS Support Distributor (ASD) for Eastern Canada.

An aluminum reduction cell consists of a rectangular steel "open box", called a potshell, lined with refractory brick that surrounds the cathode carbon blocks. The assembly serves as the cathode in the electrolysis process and as a containment vessel for the electrolyte (also known as bath) in which the alumina is dissolved and for the liquid aluminum being produced. Carbon is used as the combustible anodes which are connected to an extensive network of conductors (bus bars) that provide the electric current to the cell. The operating temperature of the cell ranges between 950° and 970°C. Typically, 150 to 300 cells are connected in series to form a potline, and a smelter has one or more potlines.

The design of an optimal cell requires a thorough understanding of the temperature and current distribution in the cell in order to minimize energy requirements. Furthermore, stable operation of the cell requires a balanced bus bar system that reduces the Lorentz forces in the liquid metal generated by the strong magnetic field from the bus bar system. The design is further complicated by the interaction between the potshell and the cathode carbon as the latter swells from sodium penetration over the life of the cell.

The ANSYS capabilities have been put to work to help in the design of reduction cells at ARDC. The following are highlights of several models:

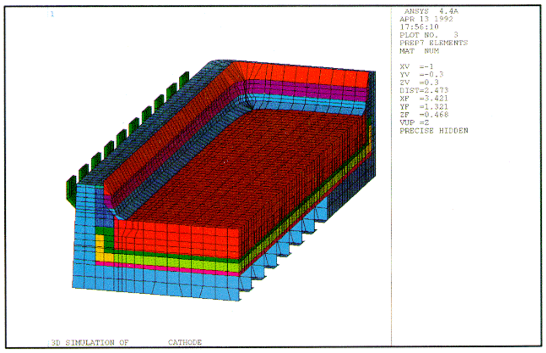

Figure 8. The prediction of the profile of frozen electrolyte on the walls of the cell is shown in the quarter cathode model mesh.

Figure 8 shows the prediction of the profile of frozen electrolyte on the walls of the cell. The precise manner by which an aluminum reduction cell loses heat depends upon the thermal insulation in the cell. Furthermore, erosion of the side wall carbon which can lead to early failure is prevented by the formulation of frozen electrolyte. A thermo-electric model of a quarter cell was developed to calculate the heat balance in the cell and predict the freeze profile. Nonlinear material properties and surface films that model convection and radiation heat transfer were used. The geometry was built parametrically to allow for easy evaluation of design alternatives.

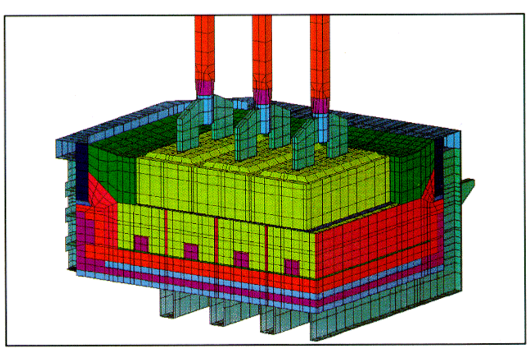

Figure 9. Evaluation of stresses in the cathode carbon during coke preheat is shown in this corner cell model mesh.

Figure 9 shows the evaluation of stresses in the cathode carbon during coke preheat. A sound preheat practice has a major effect on the life of the cathode lining. Large thermal gradients during coke preheat may crack the cathode blocks and render the cell inoperative. A good understanding of these gradients is required to minimize early failures. A transient thermo-electric model that calculated the temperature profile in a cell during a 36 hour preheat and thermal stress analysis to calculate the stress in the carbon blocks were developed. The parametric models allowed for evaluating modifications to the design as well as the operating procedures such as changing the coke bed layout, block geometry, material properties, and anode positions. A special algorithm was developed using APDL to optimize the transient time step which is controlled by the rate of temperature and voltage change in the cell. The algorithm was also used in the stress analysis to model the load transfer at the carbon-to-brick and brick-to-shell interfaces.

The evaluation of stresses in the potshell due to sodium diffusion into the cathode carbon is shown in Figure 10. Sodium ions present in the electrolyte of an aluminum reduction cell migrate into the cathode carbon blocks and cause them to

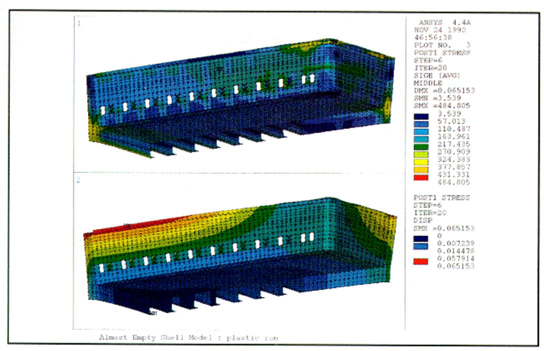

Figure 10. This shows evaluation of stresses in the potshell due to sodium diffusion into the cathode carbon quarter potshell model size stresses and deflection.

swell over time. The swelling strains increase the load on the potshell and can lead to plastic deformations that ultimately require shutting down the cell for repairs. The swelling strains are a function of the state of stress in the block which are in turn dependent on the deformation of the shell. The latter, a function of the load on the potshell wall, was developed using APDL. The elastic/plastic analysis was used to accurately calculate the pressure on the shell wall.

Figure 11 shows the development of a

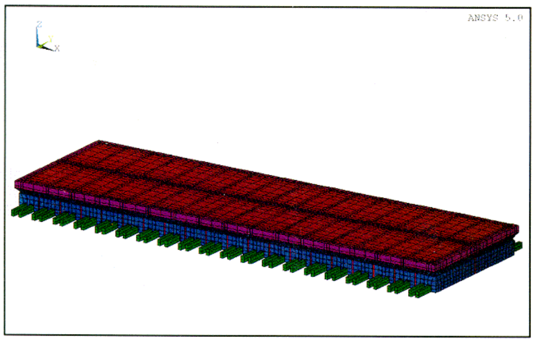

Figure 11. This is the development of a generic model to calculate the current density distribution.

generic model to calculate the current density distribution. With the enhancements made to APDL introduced at ANSYS Revision 5.0, it was possible to develop a generic parametric model of a reduction cell. The model generation, solution, and postprocessing were automated. The user input was limited to parameter values that define the cell characteristics and boundary conditions. Alternative designs could be easily analyzed and optimized using the model.

The evaluation of the Lorentz forces in the metal pad is shown in Figure 12. The introduction at ANSYS Revision 5.0 of the generalized potential approach for solving magnetic field problems and the strong coupled field capabilities of the program were being used to study the magnetic field in a reduction cell and calculate the Lorentz forces in the metal pad. Shielding effects from the ferro-magnetic steel shell were also evaluated as well as the effects of changing the current density distribution within the cell. The force field can be used to perform a stability analysis on the cell and reduce problems during operation.

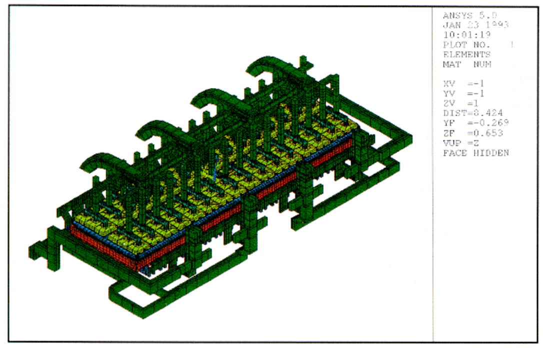

Figure 12. This full cell model mesh shows the evaluation of the Lorentz forces in the metal pad.

ANSYS capabilities have allowed Alcan's engineers to develop analysis tools that are very effective in evaluating cell designs. APDL, coupled field analysis, material nonlinear capabilities, gap elements, and portability among computer platforms are all valuable features necessary to model the complex behavior of aluminum reduction cells. The techniques used in the above models can be easily extended to other areas in the minerals processing industry.