at what height to fix the new anode stem in order to optimise the distance from anode to molten aluminium (Fig. 6).

Simpler systems using this methodology have been devised within the industry, but their inaccuracy, as far as vertical anode positioning is concerned, has led the end-users to go back to the traditional manual method. Contrary to these, ECL's system takes into account the tilting of the spent anodes during the measurement phase. Spent anodes often carry large amounts of solidified and crushed bath that make them to tilt when carried by their stem. The bottom of some anodes can also be consumed in an irregular manner, leading to an unbalance of the anode assembly. Using several sensors and a specifically developed algorithm, the PTM is able to precisely position the new anodes, in spite of the potential tilting of the spent anodes during their height measurement. Thanks to these developments, the ECL anode positioning has a precision of 3 mm with a high level of repeatability. Additionally, the floor operator does not have to come near suspended anodes or spent anodes emitting large quantities of noxious gases.

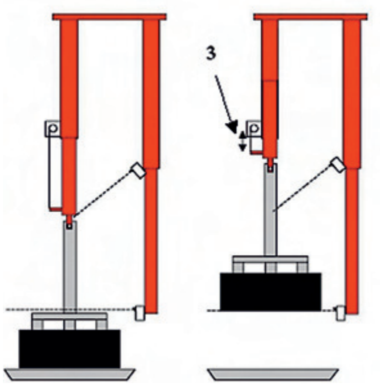

Fig. 5: Measuring the new anode height

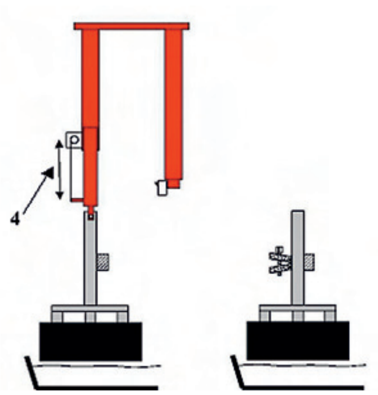

Fig. 6: Positioning the new anode

Safety, efficiency, repeatability

By combining these new tools and functions, it is now for the first time possible for the PTM operator to conduct the anode changing process without the intervention of floor operators. This avoids exposing operators to pot gas emissions, heat and dust, and much reduces the risk of collision between a PTM tool and a pot-floor operator. Taking out the human factor ensures a higher positioning precision of the various handling tasks, thereby improving the efficiency of the primary aluminium process.

Towards fully automated PTM operations

Thanks to ECL's advances, PTM design has reached a new milestone towards the fully automated PTM. Remote control and communication technologies have developed links between the building and the PTM. It is now possible to imagine that in a few years time cranes using video monitoring will work on their own in the dangerous environment of potrooms and will only require the global supervision of a remotely located operator.

Author

Nicolas Dupas is a senior B2B and B2C marketing and communication professional. He holds a master's degree in engineering and has been working in the primary aluminium industry for over six years. Nicolas is a French citizen who has an extensive knowledge of international markets and who speaks fluently English

Mathematical modelling of aluminium reduction cell potshells – improvements and applications

M. Dupuis, GeniSim

In his 2010 TMS conference paper [1], the author will present three types of 'ANSYS' based thermo-chimio-mechanical potshell models, namely the 'empty shell', the 'almost empty shell' and the 'half empty shell' potshell models. All three types of model take into account the thermal loading coming from the thermal expansion of the potshell steel structure itself by examining the thermal gradients present in the steel structure and the internal pressure due to expansion of the cell lining inside the potshell. The model versions presented in [1] were straightforward redevelopment of the work the author presented much earlier [2-5]. Since then, the author has improved all three kinds of models, taking advantage of the contact elements facilities available in ANSYS 12.0. Those improved model versions will be presented here altogether with two applications. The first application is to test a potshell retrofit design which aims to eliminate the vertical deflection of monocoque potshells. The second application is to test the potshell and lining retrofit design which the author proposed in [6] to prolong potlife up to ten years for modern high amperage cells using graphitised cathodes blocks.

Improved 'almost empty shell' potshell model

The 'almost empty shell' potshell model has been improved by →

decoupling the 2D potshell mesh from the 3D side lining mesh, and by reconnecting the two parts using ANSYS CONTA174 and TARGE170 contact pair elements. After the decoupling, it is possible to completely refine the 2D potshell mesh, something that was not possible before the decoupling. This is important because it was already demonstrated in [7] for the 'empty shell' potshell model that the initial thermo-electric model mesh [8,9] was too coarse to carry out accurate thermo-mechanical analysis. Hence, this possibility to refine the potshell mesh significantly improves the model.

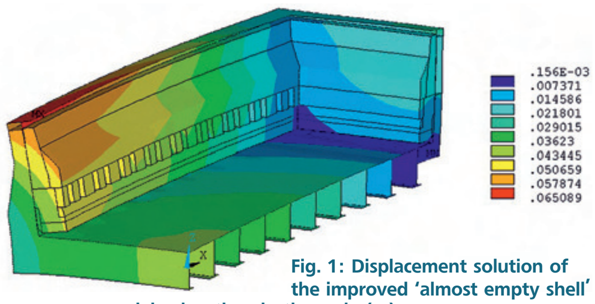

Fig. 1: Displacement solution of the improved 'almost empty shell' model using the plastic mode (m)

Images: Genisim

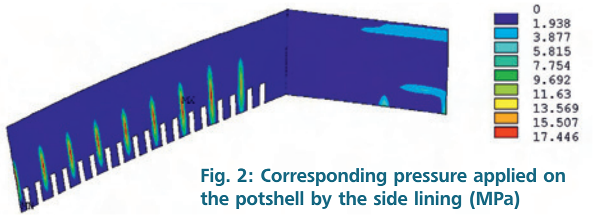

Fig. 2: Corresponding pressure applied on the potshell by the side lining (MPa)

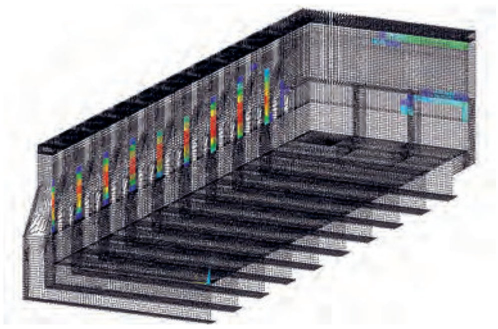

Fig. 3: Pressure applied on the 'empty shell' model potshell structure as boundary conditions

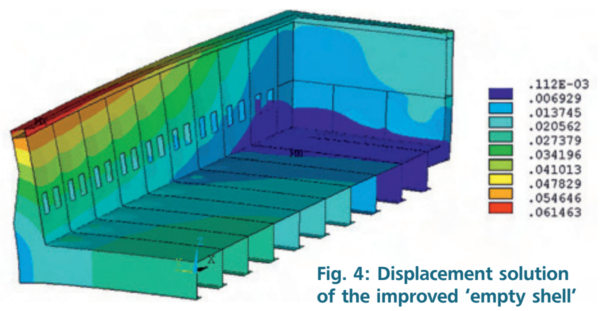

Fig. 4: Displacement solution of the improved 'empty shell' model using the plastic mode (m)

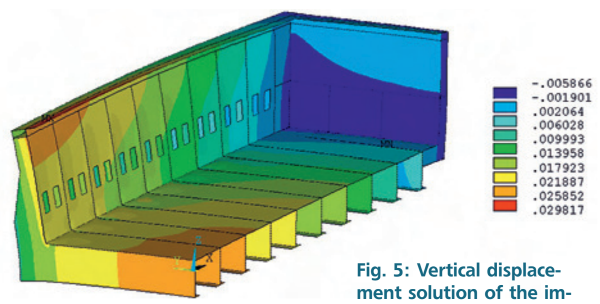

Fig. 5: Vertical displacement solution of the improved 'empty shell' model for the standard potshell design using the plastic mode (m)

Fig. 1 presents the resulting displacement solution, which is not significantly different from the one presented in [1]. Apart from the opportunity to further refine the 2D potshell mesh, a second significant improvement is that the model lets us extract from the solution the pressure that the side lining is applying on the potshell through the contact interface (Fig. 2).

Improved 'empty shell' potshell model

As discussed in [1], the main weakness of the 'empty shell' type of potshell model is that the modeler must define internal pressure load as a boundary condition, and that to do so he can only rely on semi-empirical loading schemes established from measurement campaigns. Now, the improved 'almost empty shell' potshell model provides a new possibility. Now the modeler can extract the contact interface pressure distribution from the 'almost empty shell' model solution (Fig. 3) and then use this as boundary conditions to the 'empty shell' model.

As we can see in Fig. 4, the resulting improved displacement solution is quite different from the 'empty shell' model presented in [1], and it is now quite similar to the one presented in Fig. 1. This clearly demonstrates that the semi-empirical loading scheme that the author knew and used in [1] is quite different from the pressure distribution presented in Fig. 2.

Using the improved 'empty shell' model to test a new potshell design aiming at eliminating the vertical potshell displacement

As discussed in [7,10,11], high amperage cell monocoque potshells are very long, and their vertical displacement has a negative impact on the cell operation. For quite some years now, the author had a design idea for a potshell retrofit aiming at preventing that vertical potshell displacement, and the improved 'empty shell' model is the perfect tool to test this potshell retrofit design idea. Fig. 5 presents the vertical displacement component of the standard design solution. We can see that for that 300 kA, 14 meter long potshell, the floor moves up to about 30 mm vertically. Fig. 6 presents the vertical displacement component of the retrofitted potshell: this clearly shows that the design leaves essentially no vertical displacement component due to thermal load.

Using the improved 'almost empty shell' model to test a new potshell design aiming at eliminating the vertical potshell displacement

Considering that the 'almost empty shell' model is more accurate (and hence reliable) than the 'empty shell' model, the next logical step is to test the retrofitted potshell design idea with the improved 'almost empty shell' model. Fig. 7 presents the results obtained, which are almost identical to the one obtained with the 'empty shell' model, thus confirming the validity of the idea. This also highlights the fact that, for a large number of potshell retrofit ideas not affecting the global potshell structure stiffness, the improved 'empty shell' model is the most effective analysis tool because it is the fastest tool.

Using the improved 'almost empty shell' model to test a new potshell and lining design aiming at increasing the cell life of high amperage cells lined with graphitised cathode blocks

Of course, when the proposed retrofit is changing the global potshell structure stiffness, or when the grade of cathode blocks is changed as in this second retrofit design proposal, it is not possible to use the 'empty shell' potshell model to analyse the proposed design change. This is why we must use the 'almost empty shell' model type directly this time.

In [6], the author presented a tool to model cathode panel erosion. This type of model can analyse how retrofit design changes will affect the cathode erosion and can so predict the retrofitted cell life expectancy (assuming that the first failure occurs where the liquid aluminium attacks the collector bar after corrosion has eroded all the carbon above it). That model predicted a cell life of 2,000 days for the standard design, based on the usage of 45 cm thick graphitised cathode blocks with 26 cm of carbon above the collector bars (see Fig. 8 for a full cathode panel solution of that type of erosion model).

In that same paper, the author presented a retrofit design proposal using 55 cm thick graphitised cathode blocks. It is possible to increase the cathode block thickness by 10 cm without reducing the height of the insulation under the blocks or reducing the height of the cell cavity: this simply requires moving the potshell floor 10 cm down. Lowering the potshell

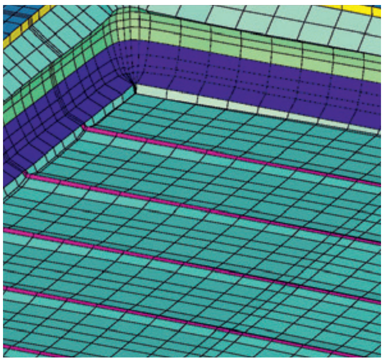

Fig. 8: Cathode panel erosion profile obtained using the full cathode panel erosion model

floor means reducing the height of the cradles web under the floor by 10 cm, thus of course reducing the stiffness of the cradles. In [6], the cathode panel erosion model calculated that with 10 cm thicker cathode blocks and selective rodding cell life would potentially increase up to 3,500 days. The paper [6] also speculated that reducing the stiffness of the cradles would not affect the potshell mechanical behaviour. This is because potshells are designed to withstand the 4 to 5% sodium swelling of amorphous cathode blocks. Consequently they have become over-designed now that graphitised blocks with sodium swelling index less than 1% have replaced amorphous blocks.

Unfortunately, the author had no potshell mechanical behaviour analysis tools available at that time to test his hypothesis, but this is of course no longer the case. So the potshell and lining design proposed in [6] has been re-analysed using the 'almost empty shell' model. In that model, one of the key parameters is ε_0, the cathode blocks' free sodium expansion value (see [1] for more details). In [1] as here, that value has so far been set to 3%, which is typical for 20% semi-graphitic cathode blocks. That parameter must be reduced in order to match the behaviour of graphitised cathode blocks, which typically expand about 1%. So the present analysis uses an expansion value of 1%.

As speculated in [6], results presented in Fig. 9 confirm the proposed retrofit design with 55 cm tick graphitised cathode blocks. The potshell will deflect less laterally than the standard design using 45 cm thick 20% semi-graphitic cathode blocks, even with the cradles web under the potshell floor having 10 cm less height.

Improved 'half empty shell' potshell model

Finally, the 'half empty shell' potshell model has also been improved by decoupling the 2D potshell mesh from the 3D lining mesh, and by greatly refining the 2D potshell mesh. Furthermore, the 3D side lining mesh has been decoupled from the 3D cathode panel mesh, by assuming that →

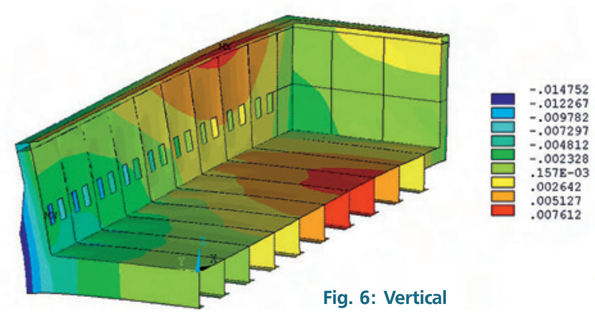

Fig. 6: Vertical displacement solution of the improved 'empty shell' model for the retrofitted potshell design using the plastic mode (m)

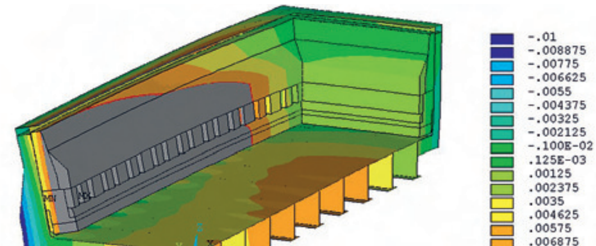

Fig. 7: Vertical displacement solution of the improved 'almost empty shell' model for the retrofitted potshell design using the plastic mode (m)

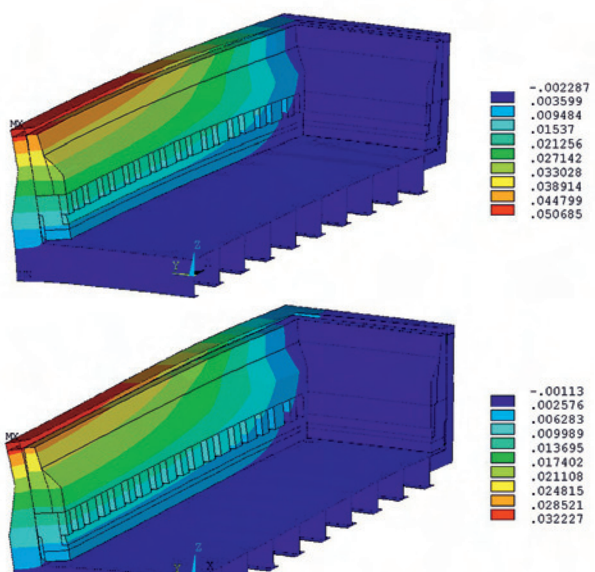

Fig. 9: Lateral displacement solution of the improved 'almost empty shell' using the plastic mode (m); top: standard potshell and lining design, bottom: retrofitted potshell and lining design

only the cathode panel swells by sodium absorption. As for the 'almost empty shell' potshell model, contact pair elements reconnect the three decoupled model parts.

The 'half empty shell' model has improved further by also taking into account the cathode panel's thermal expansion, which was not considered in the model version presented in [1].

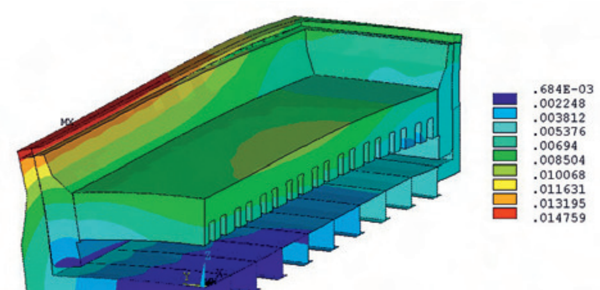

Fig. 10: Temperature only displacement solution of the improved 'half empty shell' model using the plastic mode (m)

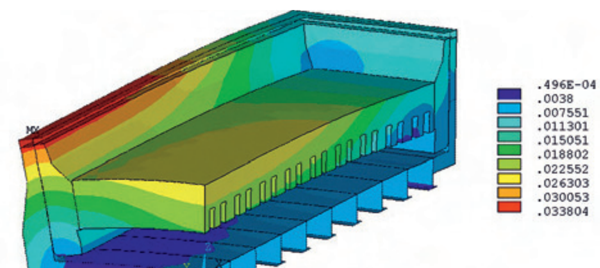

Fig. 11: Final displacement solution of the improved 'half empty shell' model using the plastic mode (m)

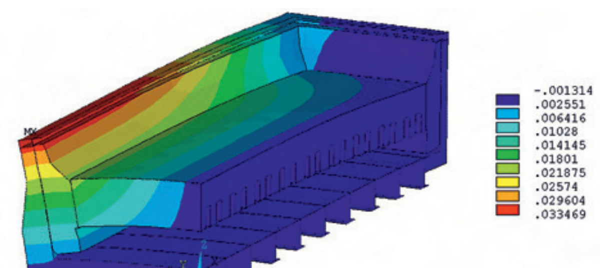

Fig. 12: Final lateral displacement solution of the improved 'half empty shell' model using the plastic mode (m)

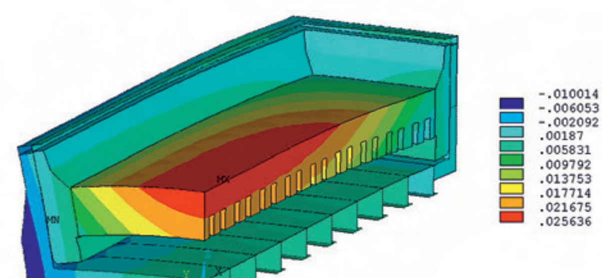

Fig. 13: Final vertical displacement solution of the improved 'half empty shell' model using the plastic mode (m)

When the sodium expansion is one order of magnitude greater than the thermal expansion, the analysis can justifiably neglect the thermal effect. But when the sodium chemical expansion is 1% or less, this justification no longer holds. So the 'half empty shell' model presented here solves the pure thermal expansion problem first (see results in Fig. 10). It then adds the transient sodium diffusion and the consequent stress level and related expansion, as presented in [1]. The final predicted potshell and lining displacements are presented in Fig. 11 for the combined design retrofit case. Fig. 12 presents only the lateral displacement, confirming the results obtained with the 'almost empty shell' potshell model for the second retrofit idea. Fig. 13 presents only the vertical displacement confirming the results obtained with the 'empty shell' and with the 'almost empty shell' potshell models for the first retrofit idea. Notice that even if the potshell itself does not deflect vertically, the cathode panel still does. The gain of cell stability between the standard design presented in [1] and the retrofitted design presented here can be analysed using MHD-Valdis as demonstrated in [11].

Conclusions

Redeveloped thermo-chimio-mechanical models [2-5] presented at the 2010 TMS conference [1] have been improved by adding up to date ANSYS contact elements technology into them. Furthermore, they have been successfully tested and confirmed two innovative retrofit design proposals, demonstrating their capability as efficient design analysis tools. Those models are now available to the whole aluminium industry through GeniSim Inc.

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Author

Dr. Marc Dupuis is a consultant specialised in the applications of mathematical modelling for the aluminium industry since 1994, the year when he founded his own consulting company GeniSim Inc. (www.genisim.com). Before that, he graduated with a Ph.D. in chemical engineering from Laval University in Quebec City in 1984, and then worked ten years as a research engineer for Alcan. His main research interests are the development of mathematical models of the Hall-Héroult cell dealing with the thermo-electric, thermo-mechanic, electro-magnetic and hydrodynamic aspects of the problem. He was also involved in the design of experimental high amperage cells and the retrofit of many existing cell technologies.