

“Two-Step” Preheating of New Anodes with Anode Butts Wasted Heat

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Abstract

In order to reduce the energy requirement to make the aluminum metal and more importantly to reduce the cell thermal perturbation of the anode change operation, it would be beneficial to preheat the new anodes using the otherwise wasted heat of the anode butts. Several methods to do so have been either experimentally tested or modeled. Some have even been patented and industrially tested. Yet none have been implemented in smelters up to now. The preheat methods imagined so far are either not sufficiently efficient or too complex to implement logistically. A new two-step preheating method has been imagined and modeled. Obtained results are presented here.

Keywords: Anode preheating, thermo-electric model, waste heat usage, FEM simulation

1. Introduction

The idea of using the wasted heat of anode butts to preheat new anodes is not new. About 10 years earlier, the opportunity to reduce the process energy requirement and to stabilize the process was investigated by Fortini, Nowicki and Gosselin, [1,2]. Industrial tests were reported in China in 2017 by Song [3], and the technology was patented in China in 2013 by Wang, H. and co-workers [4], in which it was reported that natural air convection preheating technique could bring the new anode to 80 °C in 2 to 3 hours.

A preheating technique relying on direct conduction was evaluated in tests in Norway and reported in 2020 by Grimstad, M., Elstad, K. R, Solheim, A, Einarsrud, K. E, [5]. The preheating technique required two anode butts to preheat one new anode. The work led to tests using mathematical modeling of a more efficient configuration of direct conduction preheating that turned out to be four times more efficient [6]. In the more efficient configuration, the bottom face of the new anode is placed in direct contact with the bottom face of a hot anode butt. Testing this preheating configuration in a mathematical model was not a problem but performing it in practice would have been challenging!

Up to now, no efficient and practically manageable way of preheating new anodes using the wasted heat of anode butts has been industrially implemented. The present work aims at evaluating another method to preheat anodes using heat from anode butts using mathematical modeling. That new method still relies on direct conduction preheating on the new anode bottom face, but in a “two-step” process. In the first step, the anode butt is removed from the cell and placed in an insulating box directly on top of a metal block or plate of cast iron or copper. The anode butt is kept in the box long enough for the system to reach its thermal equilibrium. After that, the anode butt can be removed at any time, the box containing the preheated metal block or plate is carefully closed, in order to maintain the achieved preheat temperature. The second step consist of putting a new anode into the box in contact with the heated metal block just at the appropriate moment before the anode change in order for the bottom face of the new anode to reach its maximum temperature. That correct moment depends on the type of metal used and the thickness of the metal block.

In this study, the modeling work was conducted using an ANSYS® 12.0 based 3D transient thermal model for 3 different metal categories put in the bottom of an insulated box: a cast iron block, a copper block and a copper plate. Modeling results indicated which of those the 3 configurations is optimum for the preheat of the new anode and corresponding maximum bottom face temperature obtained for new anodes.

2. Case 1: Cast Iron Block (225 W/m²°C)

The first configuration modeled was using a cast iron block in the bottom of the insulated box. In Case 1, the thickness of the cast iron block is the same as the thickness of the anode butt.

The initial run simulates the transient evolution of the first step where the anode butt is removed out of the cell with a bottom surface temperature of 959 °C, and put into the insulated box in contact with the cast iron block which is at potroom temperature (20 °C). Figure 1 presents the initial temperature of the anode butt (top position) and metal block (bottom) system. Figure 2 presents the final temperature of the cast iron block after 4 hours of exchange with the anode butt.

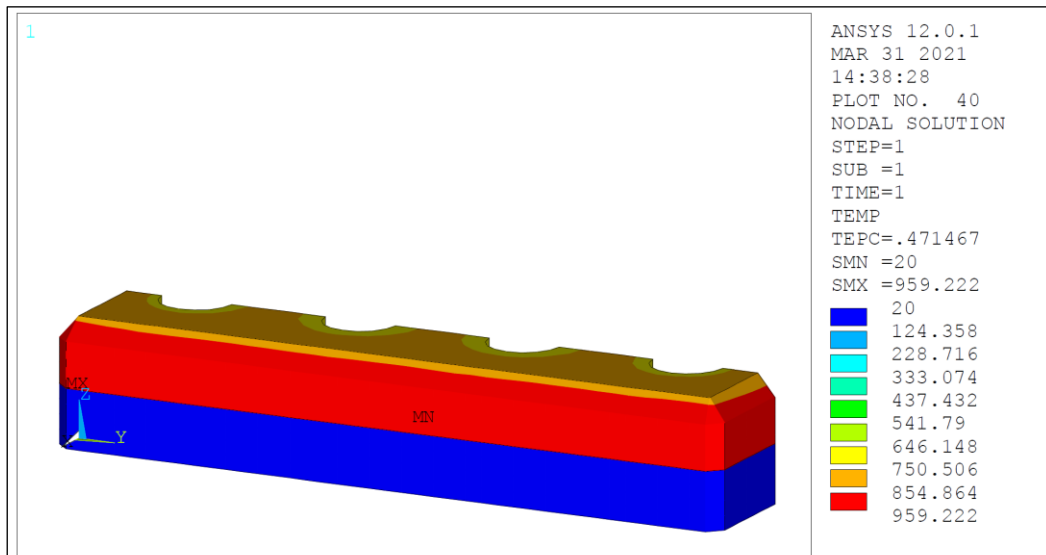


Figure 1. Initial temperature of the butt-cast iron block system for the first cycle.

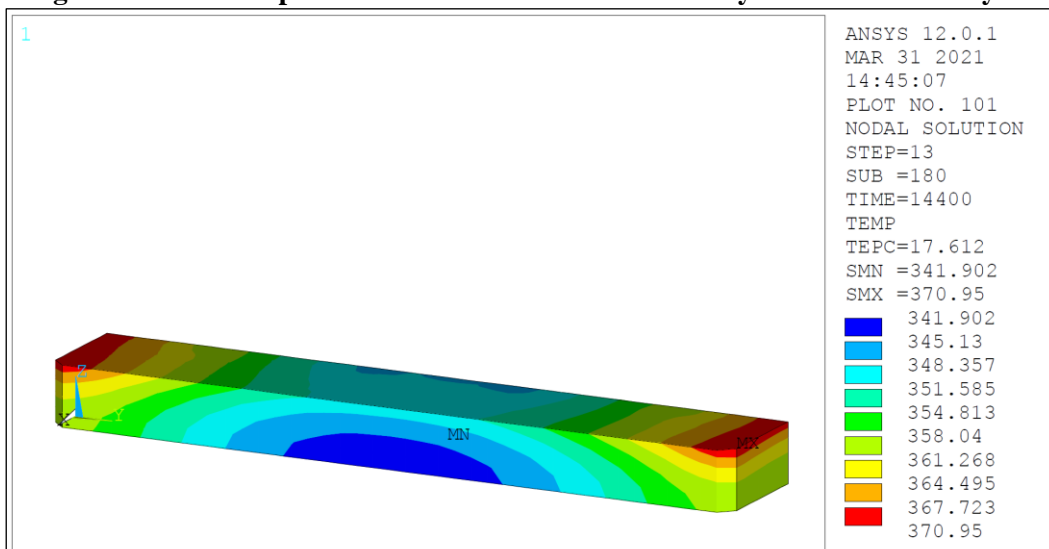


Figure 2. Temperature of the cast iron block after 4 hours for the first cycle.

In the second step of the first cycle, the bottom of the new anode is put in contact with the top of the preheated block of cast iron at that temperature. Figure 3 presents the initial temperature of that system. Notice that for the second step, to view more clearly the change in temperature isotherms in the preheated block as well as the new anode, the system is shown upside down, the cast iron is on top of the new anode. Figure 4 presents the temperature of the new anode after 4 hours of exchange with the cast iron in the insulation box while Figure 5 presents the final temperature of the cast iron for that first cycle.

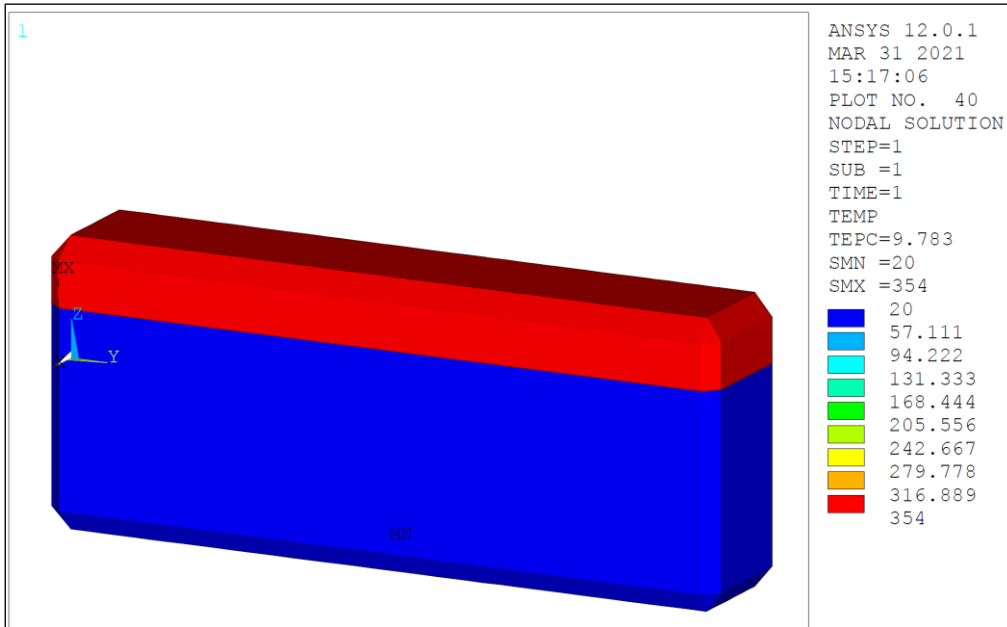


Figure 3. Initial temperature of the cast iron block-new anode system for the first cycle.

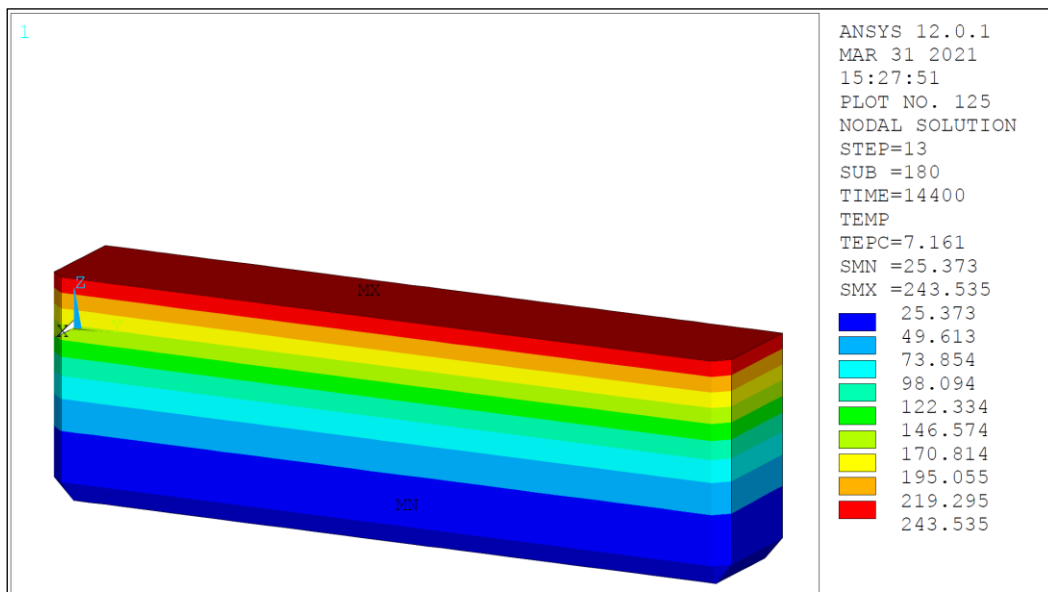


Figure 4. Temperature of the new anode after 4 hours for the first cycle.

That final cast iron block temperature is higher to the initial temperature of the cast iron block at the beginning of the first cycle and will be used as initial temperature for the second cycle. Figure 6 presents the evolution of the initial cast iron block temperature for 8 successive preheating cycles. Notice that starting at cycle 5 the duration of the exchange between the cast iron block

and the new anode was reduced from 4 hours to only 40 minutes. As a result, the cast iron started to transfer less heat to the new anode finishing the cycle warmer. More importantly, the bottom face of the new anode is finishing the cycle warmer after only 40 minutes of exchange.

From Figure 6 we can see that the pseudo steady state conditions were not quite reached for the new type of cycle having only 40 minutes of exchange in the second step, but it was decided to stop running those cycles at that point. Figure 7 presents the new anode temperature at the end of cycle 8, the average temperature is 95.51 °C, but more importantly the average bottom face temperature is 503.18 °C.

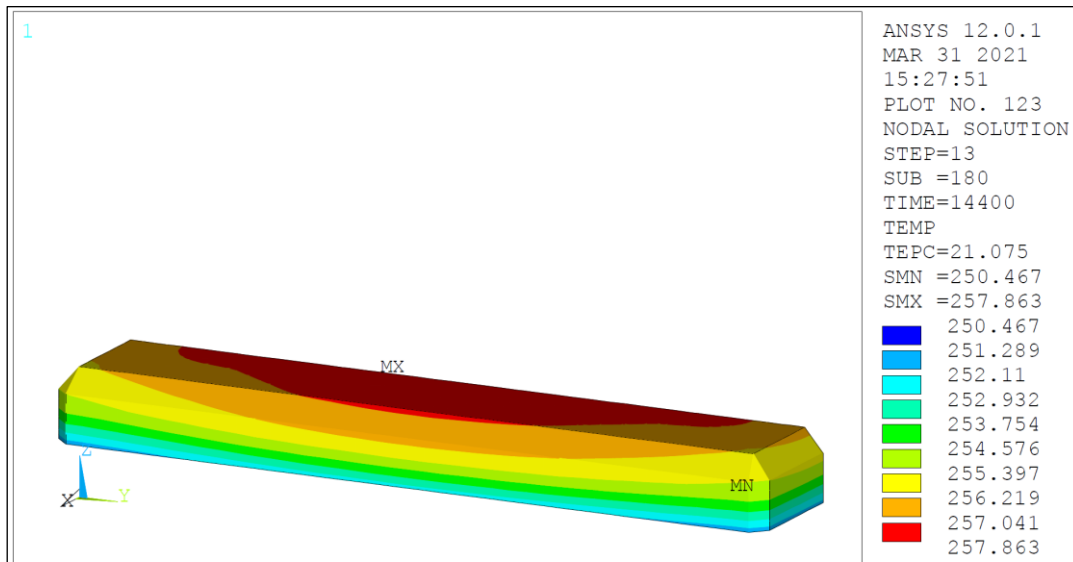


Figure 5. Temperature of the cast iron block after 4 hours for the first cycle.

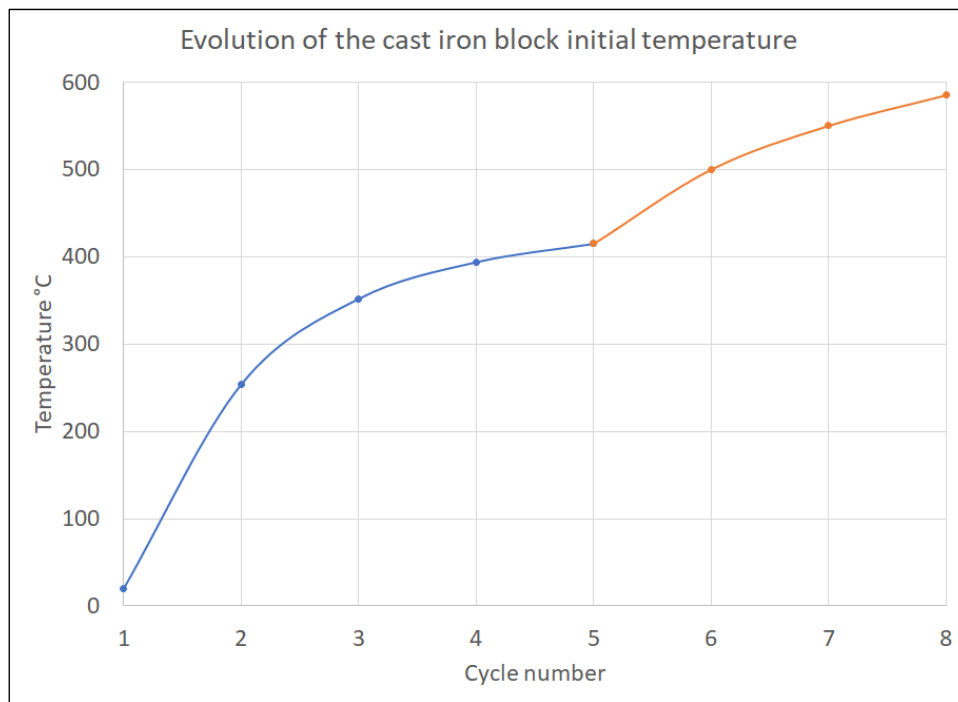


Figure 6. Evolution of the initial cast iron block temperature from cycle to cycle.

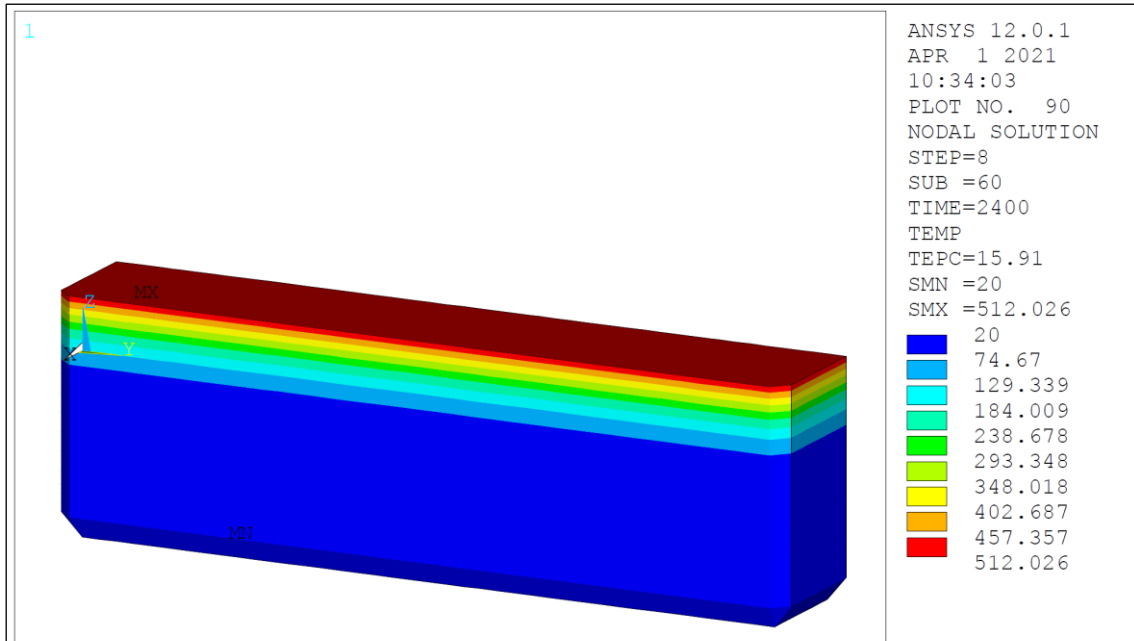


Figure 7. Temperature of the new anode after 40 minutes for the eighth cycle.

3. Case 2: Copper Block (800 W/m² °C)

The second configuration modeled is the case where a block of copper is put in the bottom of the insulated box. The thickness of that copper block is the same as the thickness of the anode butt. The initial run simulates the transient evolution of the first step where a hot anode butt just removed out of a cell is put in the insulated box with the copper block at 660 °C. That temperature was selected arbitrarily to accelerate the convergence toward the pseudo steady state condition where the temperature of the block of copper at the end of the cycle goes back to its initial temperature at the beginning of that cycle. It turned out to be a good choice as in only 4 cycles the pseudo steady state condition was reached with the copper block starting and ending the full preheat cycle at 674 °C.

Because copper is a much better heat conductor than cast iron, those cycles are much shorter, the first step with the anode butt in the insulated box is already close to equilibrium after only 1 hour and in the second step with the new anode in the box is reaching maximum new anode bottom face temperature after only 10 minutes.

In case 1, a value of 225 W/m² °C thermal contact conductance measured in [6] was used at the cast iron-carbon interface however, for case 2, an enhanced value of 800 W/m² °C was used instead for the interface. It was speculated that by pouring a film of liquid aluminum on top of the copper block at the beginning of the cycle that the copper-carbon interface thermal contact conductance could be enhanced in such a way. Unfortunately, as the new anode bottom face temperature doesn't reach 660 °C, part if not all of that the aluminum will remain frozen on that new anode bottom face when the new anode is removed from the insulated box and put in the cell. Figures 8 to 11 present the results obtained for case 2. For the final cycle in pseudo steady state condition, the average new anode temperature after 10 minutes of preheating is 69.96 °C but more importantly the average bottom face temperature is 616.64 °C.

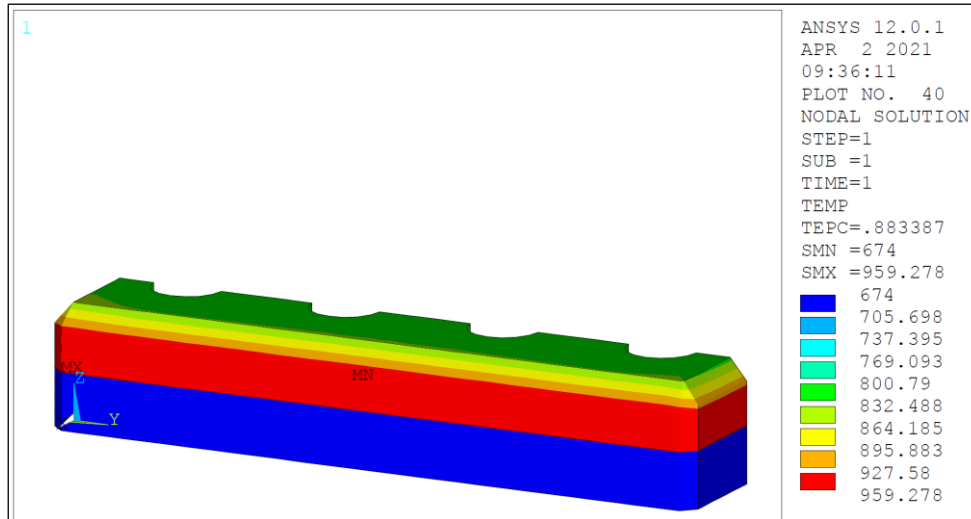


Figure 8. Initial temperature of the anode butt-copper block system for the final cycle.

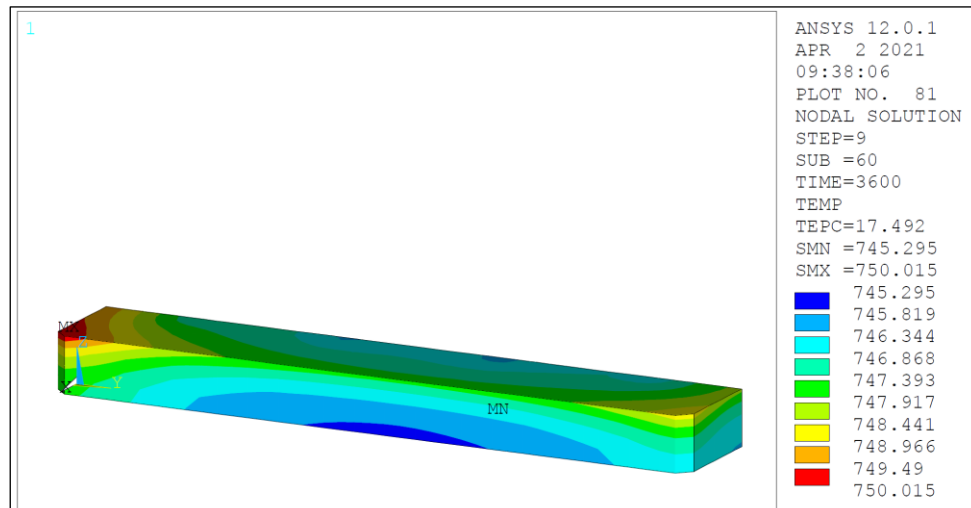


Figure 9. Temperature of the copper block after 1 hour for the final heating cycle.

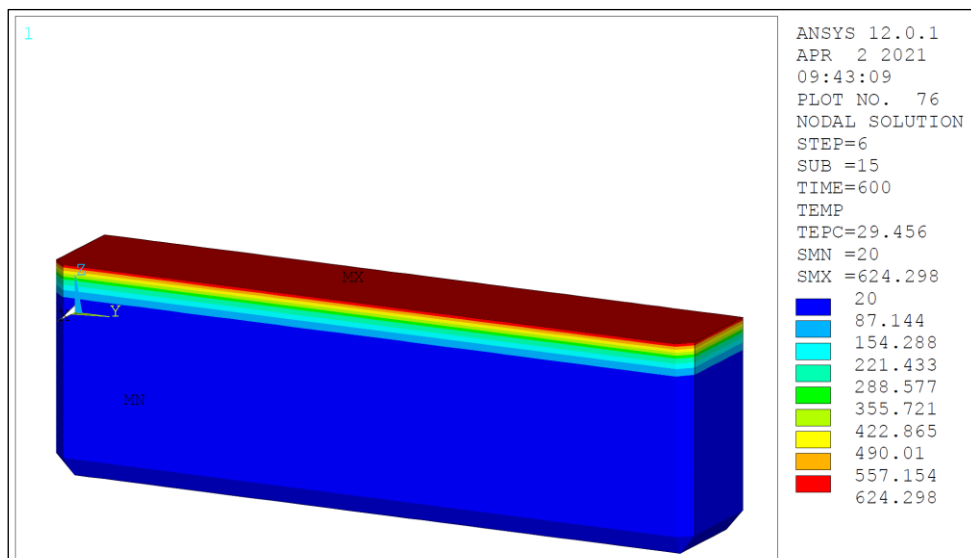


Figure 10. Temperature of the new anode after 10 minutes of preheating.

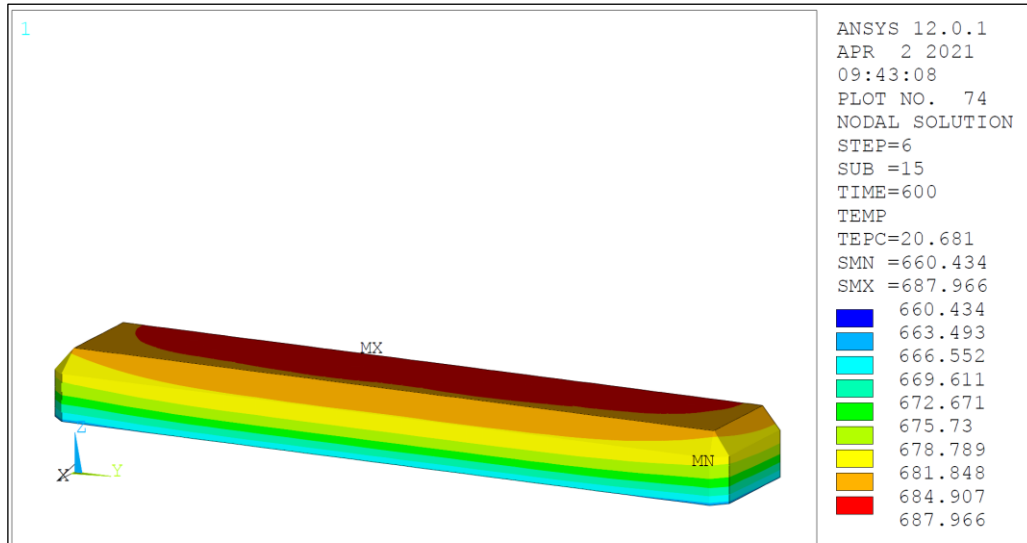


Figure 11. Temperature of the copper block after 10 minutes for the final heating cycle.

4. Case 3-a: Copper Plate (800 W/m² °C)

The third configuration modeled is the case where a copper plate is put in the bottom of the insulated box. Changing the thermal mass of the intermediary material has two impacts. First, it is increasing the equilibrium temperature of the system in the first step. Hence the anode butt can bring a copper plate to a higher temperature than a copper block. Second, the cooling rate of that intermediary material is much faster in the second step of the cycle. Hence the maximum temperature of the bottom face of the new anode is reached much faster when using a copper plate instead of a copper block.

As shown below, changing the thermal mass doesn't greatly affect the new anode maximum bottom face temperature but it significantly affects the preheat cycle duration. In turn, the preheat cycle duration have a huge impact on the logistic for the new anode change operation in cells. It proved to be that when using a copper plate and using 800 W/m² °C for the interface thermal contact conductance, the copper plate-anode butt system reaches thermal equilibrium in about 40 minutes in the first step. In the second step, the cooling rate of the copper plate is so high that the maximum temperature of the new anode bottom face is reached in only 2 minutes! So, the timing of the second step becomes quite critical, possibly creating a logistic challenge for the anode change operation in cells.

In this instance, assuming 660 °C as the initial temperature of the copper plate was not a good estimate, as indicated in Figure 12; the pseudo steady state initial copper plate temperature is above 734 °C after 4 full preheat cycles. The results obtained for the copper plate case when 800 W/m² °C is used for the interface thermal contact conductance in the final cycle is shown in Figures 13 to 16.

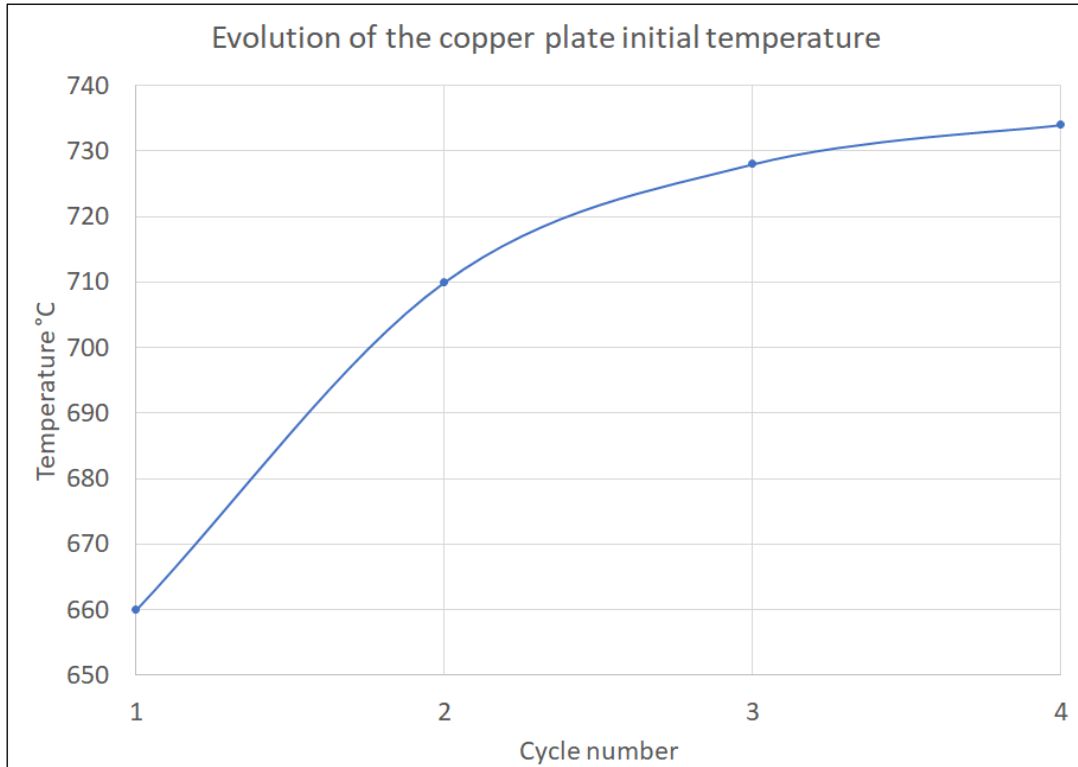


Figure 12. Evolution of the initial copper plate temperature after heating cycles.

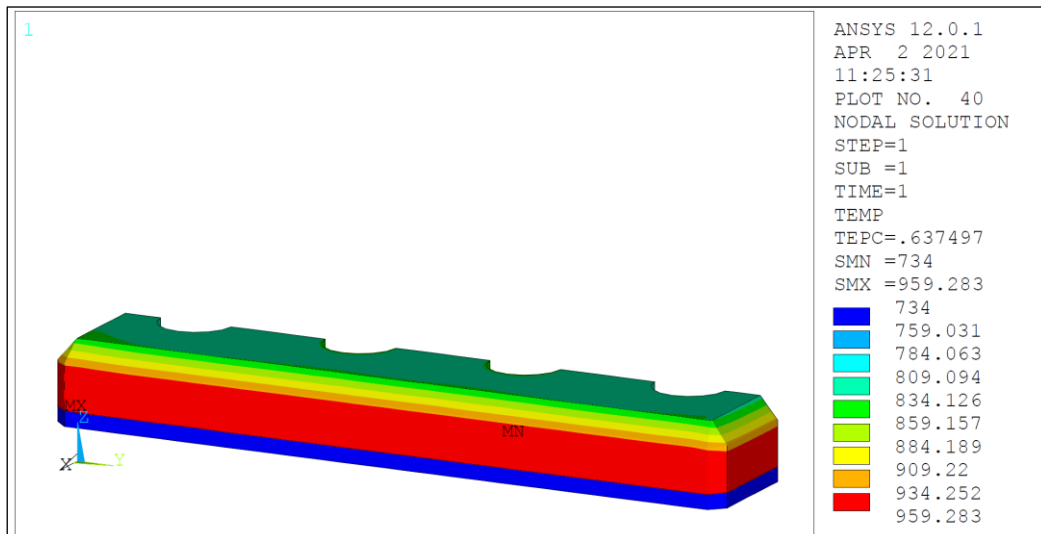


Figure 13. Initial temperature of the anode butt-copper plate system for the final heating cycle.

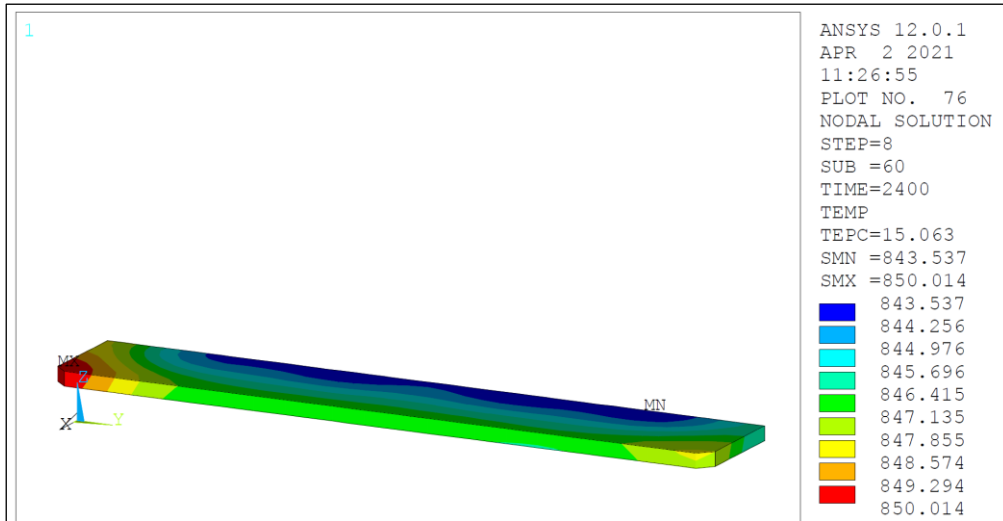


Figure 14. Temperature of the copper plate after 40 minutes for the final heating cycle.

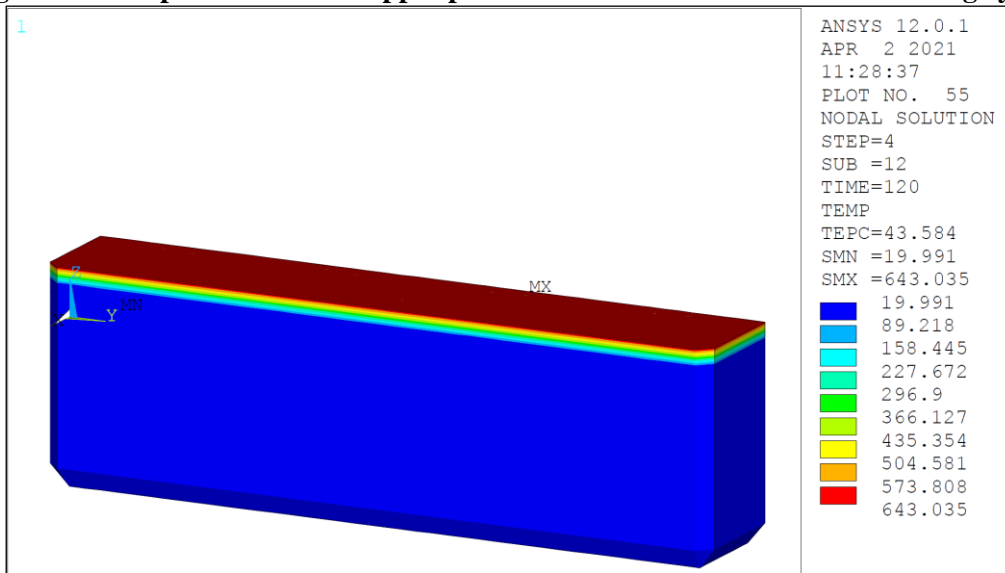


Figure 15. Temperature of the new anode after 2 minutes of preheating.

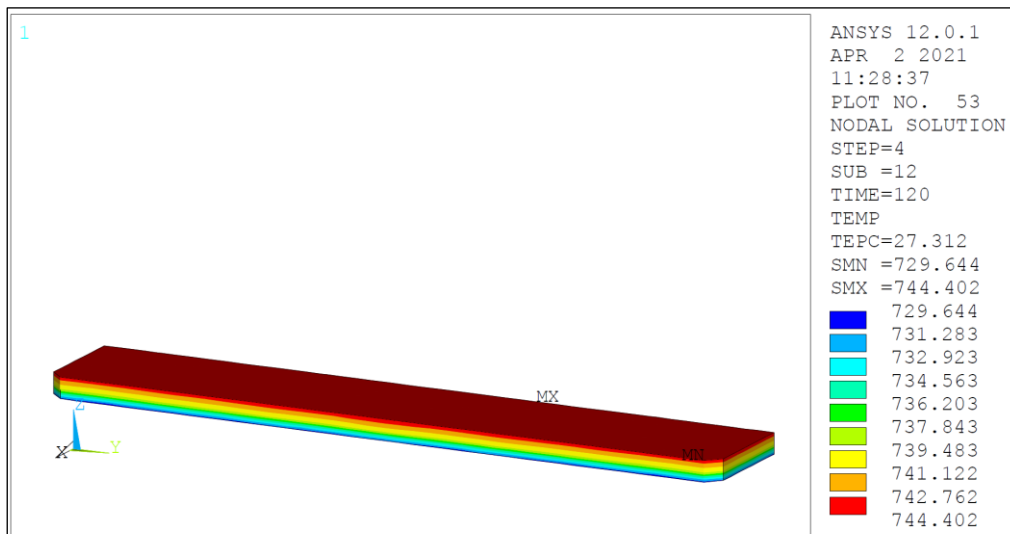


Figure 16. Temperature of the copper plate after 2 minutes for the final cycle.

For the final cycle in pseudo steady state condition, the average new anode temperature after 2 minutes of preheating is 48.00 °C but more importantly the average bottom face temperature is 618.65 °C. Thus, it is 2 degrees higher than with the copper block in only 2 minutes instead of 10 minutes. After reaching the maximum bottom face temperature, the temperature starts to decrease quite rapidly making the perfect timing of sequence with the anode change operation critical.

5. Case 3-b: Copper Plate (225 W/m²°C)

Considering that rapid preheating of the bottom face could possibly introduce some anode cracking problems especially for anode not having slots, a final anode preheat cycle was modeled using the measured 225 W/m²°C for the interface thermal contact conductance. The change of value of interface thermal contact conductance does not affect the final conditions of first step of the cycle as the system equilibrium temperature is not affected by that parameter. However, it considerably affects both the new anode bottom face maximum temperature and the time required to reach that maximum temperature in the second step.

When using 225 W/m²°C, the average new anode temperature after 10 minutes of preheating is 60.90 °C but more importantly, the average bottom face temperature is 531.47 °C as seen in Figure 17.

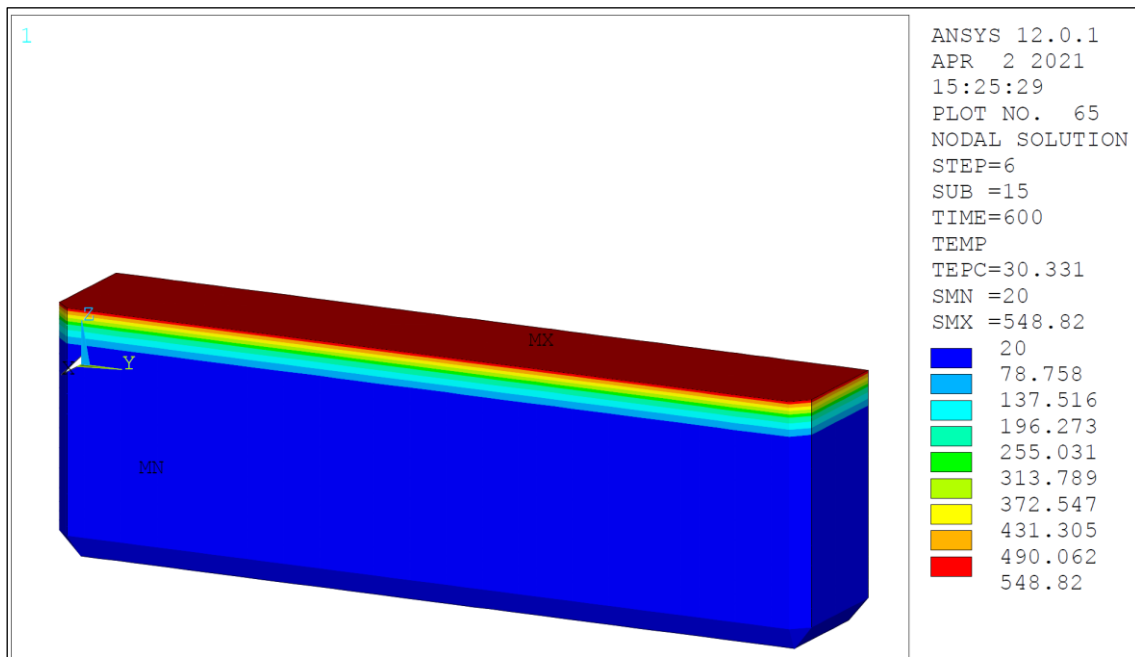


Figure 17. Temperature of the new anode after 10 minutes of preheating with the modified 225 W/m²°C interface thermal contact conductance.

6. Anode Change Sequence with the “Two-Step” Preheating of Anodes

A summary of the results of the thermal modeling of the two-step heat transfer process using different metals is shown in Table 1. In the first step of the anode change sequence of the new anode "two-step" preheating process, a hot anode butt is removed from an operating aluminum cell and placed into an insulated box with the hot bottom surface of the anode butt in direct contact with a metal block or plate. In this manner, heat is transferred directly from the hot bottom surface of the anode butt (960 °C) into the metal block or plate (20-740 °C). After an appropriate time,

typically 40 minutes to 4 hours, the metal-carbon system reaches a thermal equilibrium, and the hot anode butt is removed from the box at a time after that.

In the second step of the new anode “two-step” preheating process, a new anode (20 °C) is placed in the insulated box with the bottom surface of the anode in direct contact with the top surface of the heated metal block or plate. Heat is transferred directly from the hot metal block or plate into the bottom surface of the new anode. After an appropriate time, 2 to 40 minutes, the bottom surface temperature of the new anode increased to 503 to 619 °C depending on the values used for the copper-carbon interface thermal contact conductance (800 vs. 225 W/m² °C). The preheated new anode is removed from the box and installed into an operating aluminum cell. The “two-step” anode preheating process proceeds in a continuous manner during the normal anode change operation in potrooms.

Table 1. Summary of the new anode “two-step” preheating modeling results using cast iron and copper as heat transfer medium.

	Initial Block or Plate Temp. °C	Interface Thermal Contact Conductance W/m ² °C	Anode Preheat Time minutes	Avg. New Anode Temp. °C	Avg. Bottom Surface Temp. °C
Case 1 Cast Iron Block	559 @ 8 cycles	225 (iron-carbon)	40	96	503
Case 2 Copper Block	674 @ 4 cycles	800 (copper-carbon)	10	70	617
Case 3-a Copper Plate	734 @ 4 cycles	800 (copper-carbon)	2	48	619
Case 3-b Copper Plate	734 first cycle	225 (copper-carbon)	10	61	532

7. Conclusions

A new “two-step” indirect process to preheat new anodes with the waste heat of anode butts has been developed and evaluated using ANSYS® 12.0 based 3D transient thermal mathematical model.

In the first step, enough time must be allowed for the system to reach thermal equilibrium, that minimum time is 4 hours for the cast iron block, 1 hour for the copper block and 40 minutes for the copper plate. After that minimum time, the system state doesn’t evolve anymore so the anode can be removed from the insulated box at any convenient time after that.

Later, in the second step, a new cold anode is placed in the box at the appropriate time as part of the anode change operation. The bottom surface of new anodes in direct contact with a hot cast iron block is preheated to 503 °C after 40 minutes using 225 W/m² °C for the cast iron-carbon interface thermal contact conductance. By comparison, the bottom surface of new anodes in direct contact with a hot copperplate is preheated to 619 °C after only 2 minutes using 800 W/m² °C for the copper-carbon interface thermal contact conductance.

The new anode “two-step” preheating process is almost as efficient as the direct new anode preheating previously evaluated by Dupuis [6] using mathematical modeling. The new anode “two-step” preheating process introduces more flexibility to develop a preheating cycle that could be practically implemented when changing anodes during regular smelter operations.

8. References

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