Modelling of Cast Iron to Carbon Electrical Contact Resistance to Reproduce Anode Voltage Measurements

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Abstract

Anode voltage (or anode assembly voltage) is an important component of the voltage breakdown of an electrolysis cell. It contributes to the specific energy consumption of the produced aluminium and to the cell internal heat generation required to maintain the right operating temperature and ledge protection. In general, it is beneficial to reduce the anode voltage to save energy or generate heat in the ACD rather than in the anode. High anode voltage may also reflect poor distributions of anode current density or mechanical stresses which enhance the probability of anodic incidents such as cracks and burn-offs. Nevertheless, anode voltage correlates with the anode thermal resistance which contributes to the cell top heat loss and thus reducing the anode voltage does not necessarily mean a lower cell voltage assuming the same thermal balance.

The main components of the anode voltage are the yoke and stubs voltages including the clad voltage, the stub to cast iron contact voltage, the cast iron voltage, the cast iron to carbon contact voltage and the carbon voltage. They can be easily determined numerically from temperature and current density fields knowing temperature-dependent material properties, except for the contact voltages. We assume that the cast iron to carbon contact voltage depends on the contact pressure between cast iron and carbon at operating temperature which in turn is a function of the air gap resulting from the cast iron and stub shrinkages after anode rodding. The coupled thermoelectric-mechanical problem is solved to compute the anode voltage. The law relating the contact surface resistivity and the contact pressure is calibrated based on measurements over the cycle of Reference anodes and validated based on measurements over the cycle of so-called "Big Foot" anodes having different stub and stub hole geometries. Mechanisms responsible for the anode voltage breakdown as a function of yoke, stub, stub hole, carbon block designs and anode age are highlighted. Similar models can also find application in cathode design which also involves a cast iron to carbon electrical contact.

Keywords: Anode voltage measurement, Cast iron to carbon electrical contact resistance, TE-MEC modelling, Stub hole design, "Big Foot" anode.

1. Introduction

Electrical contact between conductor surfaces is achieved by contact points which carry the electrical current and reduce the effective contact area. The electrical contact, despite a very short length, is characterized by a voltage drop which can be modelled by an electrical contact resistance. The stub to cast iron contact resistance is generally assumed to be negligible and the focus is laid on the cast iron to carbon contact (both being difficult to distinguish experimentally). In previous modelling work [1], the electrical contact resistance between cast iron and carbon is assumed to depend on the pressure between the contact surfaces. The contact pressure results from the lifting of the anode by the anode rod and by the heating of the anode from ambient temperature to operating temperature. It depends on the anode geometry (including the air gap between cast iron and carbon consecutive to rodding), on the operating temperature and current density fields and on the material properties of the anode components (electrical and thermal conductivities, thermal expansion coefficient, Young's modulus). Thus, a coupled thermoelectrical-mechanical problem must be solved to compute the anode voltage. In practice, the cast iron to carbon electrical contact resistance of a given anode design is often calibrated based on anode voltage measurements. However, this approach loses its predictive capability in case of change of anode design or material properties.

2. Models

2.1 Reference

An existing anode assembly called hereafter the Reference anode has been modelled including: clad, yoke, stubs, cast iron, air gap, carbon block, anode cover, crust, bath and metal layers with respective material properties at three different anode ages (7, 14 and 21 days). The carbon block height as a function of anode age has been computed based on new anode and butt heights (see Figure 1). It is assumed that only the height of carbon block and crust layer is affected by anode age, the carbon block cross section being unchanged. The decrease in crust thickness with anode age is a consequence of the assumed constant anode cover thickness.

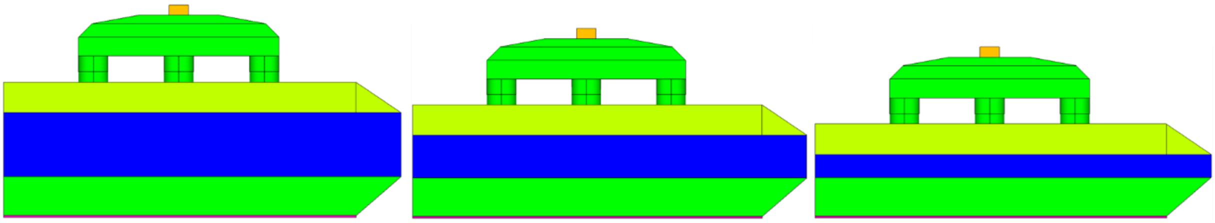

Figure 1. Reference anode assembly model: 7, 14 and 21 days.

The air gap between cast iron and carbon at ambient temperature results from the shrinkage of cast iron and stubs after rodding and from the downward movement of the carbon block when the anode is lifted (due to the air gap on the flutes sides, carbon block is supported by the upper flutes side). The air gap is not uniform across the contact surfaces due to the varying cast iron thickness and flute width over the stub hole depth. The air gap between the flutes and at the flute tip is the sum of the cast iron and stub shrinkages as expressed in Equation 1.

$$\begin{aligned} gap &= \Delta r_{stub} + \Delta d_{cast-iron} \\ &= r_{stub} \cdot \alpha_{steel} \cdot (T_{stub} - T_{amb}) + d_{cast-iron} \cdot \alpha_{cast-iron} \cdot (T_{cast-iron-solid} - T_{amb}) \end{aligned} \tag{1}$$

where:

r_{stub}	Stub radius, m
$d_{cast-iron}$	Cast iron distance, m
α_{steel}, $\alpha_{cast-iron}$	Thermal expansion coefficients, °C^{-1}
T_{stub}	Stub temperature before rodding, °C
$T_{cast-iron-solid}$	Cast iron solidification temperature, °C
T_{amb}	Ambient temperature, °C

On the flute sides, the air gap is only made by the shrinkage of cast iron $\Delta d_{cast-iron}$ with $d_{cast-iron}$ being the flute width. In contrast to [1], the contact pressure is also computed below the stubs and current is allowed to flow from stub end to carbon assuming the same contact resistance as between cast iron and carbon.

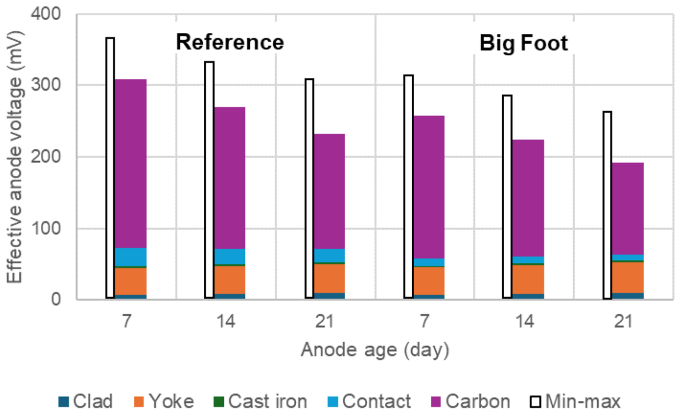

Figure 8. Computed min-max anode voltage and effective anode voltage breakdown at 7, 14 and 21 days for Reference and Big Foot anodes.

Table 1. Computed min-max anode voltages and effective anode voltage breakdown at 7, 14 and 21 days for Reference and Big Foot anodes.

	Anode age day	**Min-max** mV	**Effective** mV	**Clad** mV	**Yoke** mV	**Cast iron** mV	**Contact** mV	**Carbon** mV
Reference	7	365	309	7	37	3	25	237
	14	331	269	8	39	3	22	198
	21	307	232	9	41	3	19	161
Big Foot	7	312	258	7	38	2	10	200
	14	285	224	8	40	2	10	163
	21	263	191	9	43	2	9	127

4. Conclusions

A model for the electrical contact resistance between cast iron and carbon is proposed and calibrated based on anode voltage measurements by solving the thermoelectric-mechanical problem of an anode immersed in bath and conducting electrical current to a metal layer. The model has been validated by computing an alternative anode design which was tested at TRIMET Essen smelter. The computation results highlight the mechanisms responsible for the variations in anode voltage breakdown as a function of anode design and age.

Based on our experience of Hall-Héroult cell technologies, cast iron to carbon contact voltage ranges from 20 mV as for the Reference anode to up to 100 mV depending on anodic current density and anode design. As demonstrated with the Big Foot anode, the voltage drop over the cast iron to carbon contact can be reduced by stub and/or stub hole design changes but the voltage drop in the carbon block can be decreased to an even larger extent if the current density around the stub hole is made more uniform. Heat loss through the yoke and the anode cover has not been studied here but should be part of the full analysis to make sure that the anode voltage saving can be recovered in the cell voltage.

5. References

1. Daniel Richard et al., Challenges in stub hole optimisation of cast iron rodded anodes, *Light Metals*, 2009, 1067–1072.