

Innovation of Prebaked Anode Design to Enhance Productivity

**Victor Buzunov¹, Victor Mann², Igor Cherskikh³, Andrey Soldatov⁴,
Sergey Koshkarev⁵, John Johnson⁶ and Andrey Zavadyak⁷**

1. Director, Aluminium technology & technical implementation, ETC RUSAL, Krasnoyarsk, Russia
 2. Technical Director, UC RUSAL, Moscow, Russia
 3. Head of Anode Group, ETC RUSAL, Krasnoyarsk, Russia
 4. Director of department, ETC RUSAL, Sayanogorsk, Russia
 5. Director of department, ETC RUSAL, Irkutsk, Russia
 6. Consultant, ETC RUSAL, Krasnoyarsk, Russia
 7. Project Director ETC RUSAL, Krasnoyarsk, Russia
- Corresponding author: Victor.Buzunov@rusal.com

Abstract

Prebaked anode consumption depends not on physical-chemical properties of the anode as it is, but also by its shape and dimensions. Previously to reduce non-electrolytic consumption of carbon material the upper part of the anode in RUSAL Company had a 100 mm high “lip”. The main shortcoming of this shape is increased burn off rate at the end of the anode cycle, dusting, exposure of stubs to the bath, reduced effective area of the anode, and disturbance of current distribution in the anode carbon. To eliminate these shortcomings optimum anode configuration was mathematically modeled and tested in experimental areas: the lip was diminished, the stub hole was made deeper and the height and width of the anode were increased. Anodes with this configuration showed improved efficiency. Anodes with modified design were used in all potlines with prebaked anodes. Changes in the shape helped reduce anode consumption by 5 – 7.5 kg/t Al and electric energy consumption by 85 to 290 kWh/t Al (depending on the cell type).

Keywords: Prebaked anode, anode shape, butts, anode consumption, anode reactivity.

1. Introduction

It is common knowledge that the main contributors to consumption of prebaked anodes are their physical-chemical properties, cell design and electrolysis variables. Figure 1 shows classical diagram of anode consumption from the paper by Werner Fisher [1], it also gives an equation that helps evaluate contribution of each component of anode net consumption.

$$NC = C + \frac{334}{CE} + 1.2(T - 960) - 1.7CRR + 9.3AP + 8TC - 1.5ARR \quad (1)$$

where: *NC* Net carbon consumption, kg C/t Al
C Cell factor (270 – 310 defined empirically)
CE Current efficiency, %
T Bath temperature, °C
CRR CO₂ reactivity, %
AP Air permeability, nPm
TC Thermal conductivity, W/mK
ARR Air reactivity, %.

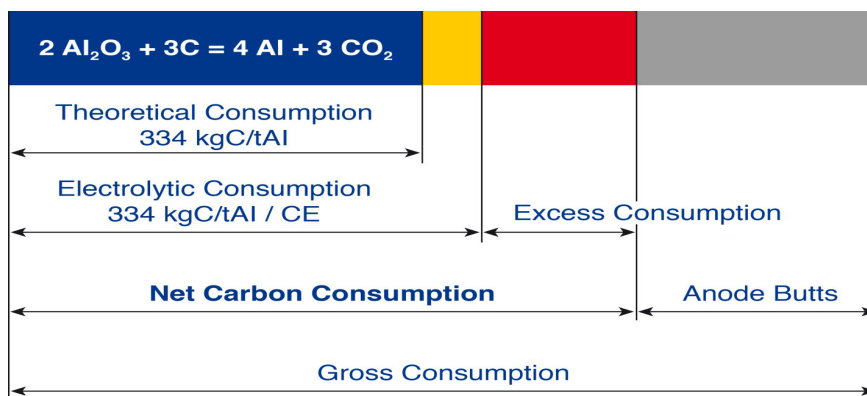


Figure 1. Anode consumption diagram [1].

The anode consumption is largely affected by its shape, configuration of its top, height, length, width and their ratio, stub hole depth, the shape of its faces, height, width and location of slots.

Anode production and the purchased anode cost have a big effect on the cost of aluminum production. Their share varies with companies from 12 to 14 %. Therefore, every producer is searching for its optimum anode shape matching the cell design and meeting commercial requirements when purchasing anode blocks elsewhere: As a minimum, this involves shape and size unitized for different cell types and balance between the minimum of the mass and cycle length.

Anode shapes used in the world are numerous, some of them are shown in Figure 2.



Figure 2. Prebaked anodes of various forms [2].

This article describes causes and results of this conversion a new anode shape.

2. Motivation for Anode Shape Modification

Until 2015, as it was thought at that time in RUSAL plants, to reduce non-productive consumption of carbon material, the section on the upper part of the anode was decreased by a 100 mm high “lip” (Figure 3).

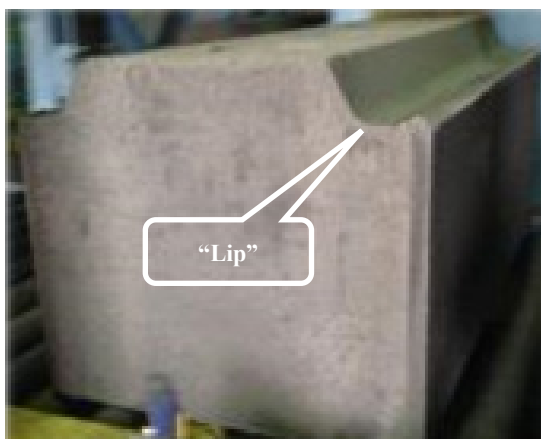


Figure 3. Anode with 100 mm “lip”.



Figure 4. Butt of anode with “lip”.

During operation on individual prebaked anodes in several last days of the cycle the air burn and/or disturbance of current distribution frequently decreased the butt so much that it was practically covered with a layer of bath. This butt was impregnated with cryolite-alumina melt and the anode assembly stub was intensively electrochemically dissolved and deteriorated. The so called “soft” butts impregnated with bath components were reclaimed. Impregnated butts increased the amount of catalytic Na and Ca impurities in the anodes and increased their burn off rate. Low quality of the anodes also was the cause of their dust loss, dusting, and increased carbon concentration in the bath which increased bath resistance. Increased resistance reduces anode-cathode distance, disturbs current distribution and results in emergence of spikes on the anode bottom. This again increased the burn off rate and provoked further decrease of butt height, increasing their impregnation with bath salts. Small quantity of anodes with anomalously small butts could trigger the feedback mechanisms which deteriorated anode quality and the problems extended over the entire electrolysis production. R&D Centre experts call such cyclically emerging problems “carbon crises”; Figure 5 shows a diagram of carbon crisis development from [3]. To get out of carbon crisis it takes 2 – 3 months and it is necessary to temporarily decrease the anode cycle. The top priority is to minimize anode dusting. According to Meier and Perruchoud [6], the damage from high dusting can amount to approximately 63 \$/t Al.

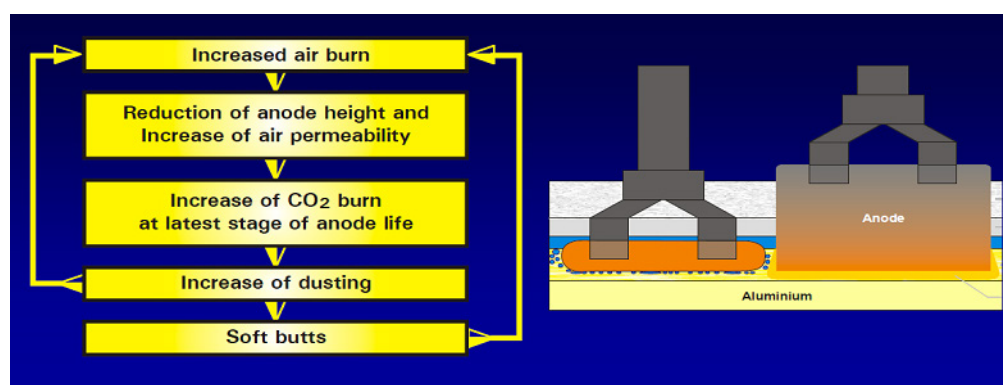


Figure 5. Carbon crisis development mechanism.

It is obvious that, other conditions being equal, the probability of such a crisis will depend on the resistance of the anode top to air reactivity. So, RUSAL specialists posed the problem to find an optimum shape of the anode to compromise between:

- The resistance of the anode top and

- Its mass.

For this purpose, different versions of anode shapes were evaluated using mathematical modeling and the shapes showing the highest potential were tested in experimental areas.

3. Mathematical Modeling

Mathematical modeling was carried out on thermal and electrical models based on ANSYS software for a 300 kA cell. Numerous versions considered included different geometrical dimensions of the blocks, height of the “lip”, faceted anode edges and without them, etc.

The optimum shape selection criteria used were for:

- Minimum bath temperature,
- Minimum cell voltage,
- Minimum possible anode-cathode distance,
- Minimum electric energy consumption,
- Maximum current efficiency,
- Optimum amperage running through the butt,
- Anode block voltage drop,
- Uniform current distribution on the anode bottom.

Table 1 presents some results of mathematical modeling, specifically, dependence of bath temperature, cell voltage, anode voltage drop, amperage in the butt on the lip height.

Table1. Some results of modeling the effect of lip height.

Height of the top lip mm	Anode current, A	Bath temperature, °C	Pot voltage, V	Anode voltage drop, V
0	8851	957	4.480	0.349
50	8822	958	4.480	0.352
70	8815	956	4.490	0.356
100	8790	955	4.518	0.366

Figure 6 shows the distribution of current densities over the anode bottom.

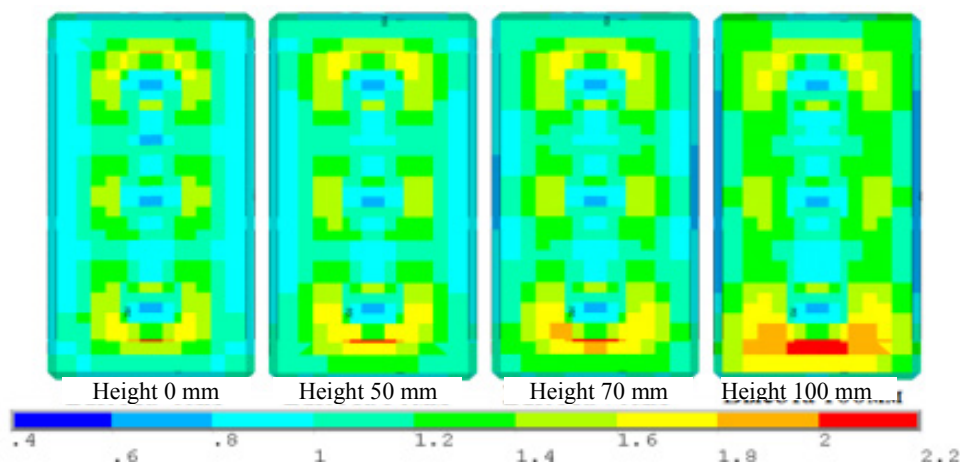


Figure 6. Distribution of current densities (A/mm^2) over the anode bottom with different lip height from 0 to 100 mm.

Figure 6 shows that as the “lip” height decreases the current density over the anode bottom is observed to redistribute. At maximum “lip” height the current density at the anode center increases and the current density over its periphery decreases – this is due to deteriorating conditions for the current to distribute over the anode block volume. This situation aggravates with the wear of the anode block. Besides, the mathematical model showed that given the width of the main part of the butt up to 50 mm, the current in the peripheral zone is practically zero, the difference increases by about 14 mV, as compared to the butts 50 mm thick in their main part.

Modeling results helped define anode configuration which met the two above mentioned requirements (Figure 7), with the lip 50 mm high and two slots.

4. Industrial tests

To make the decision to convert to the new anode shape Krasnoyarsk and Irkutsk RUSAL smelters arranged experimental areas where the anodes with new shapes were tested for 3 months. The tests evaluated efficiency of anodes in electrolysis production, feasibility of the areas to prepare and rod the anodes with modified shape, butt cleaning and stripping. Tests carried out in electrolysis production showed that the height of the butts on new anodes was 2 - 3 mm higher; this made possible to increase the cycle by 1 day and reduce gross anode consumption by 5 kgC/t Al (Figure 8).

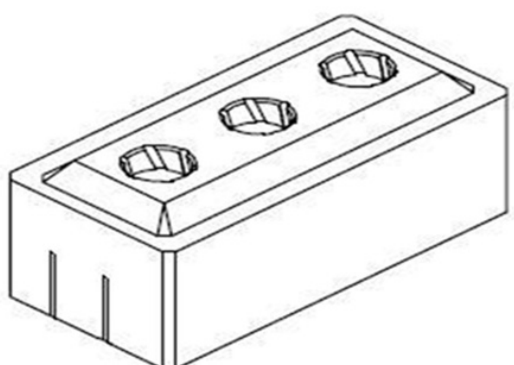


Figure 7. New shape of the anode with 50 mm “lip”.



Figure 8. Anode butt with 50 mm “lip”.

Along with improvement of technical and economic performance of electrolysis production of anodes with new shape (Figures 9 and 10), it also improved the quality of butts used as scrap in anode production and stabilize characteristics of homemade prebaked anodes. The plots show improved performance:

- CRR – average level increase from 89.6 to 92.2 %; the part of deviations below the limit of 87 % decreased 3 times – from 25.4 to 6.8 %;
- ARR – increased from 73.8 % to 81.3 %; the part of deviations below the limit of 70 % also decreased 3 times – from 33.5 to 10.9 %.

To produce anodes of new shape Sayanogorsk smelter (SAZ) replaced tooling of vibrating presses, replaced anode grabs on stacking cranes and hoisting mechanisms and installed slotting machines. After organization of production at SAZ and plants supplying anodes of modified design all prebaked anode potlines were converted to new anodes. These changes reduced anode consumption, average noise level and anode voltage drop and consequently, electric energy consumption. Main results increasing efficiency of raw aluminum production at the plants with

prebaked anodes: reduced energy consumption – from 85 to 290 kWh/t Al, reduced consumption of prebaked anodes – from 5 to 7.5 kgC/t Al.

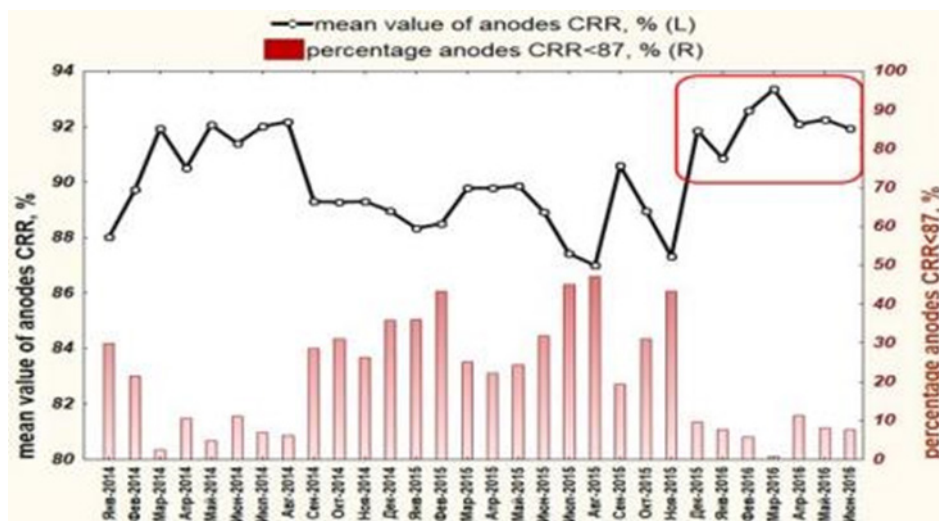


Figure 9. Variation of CRR of prebaked anodes.

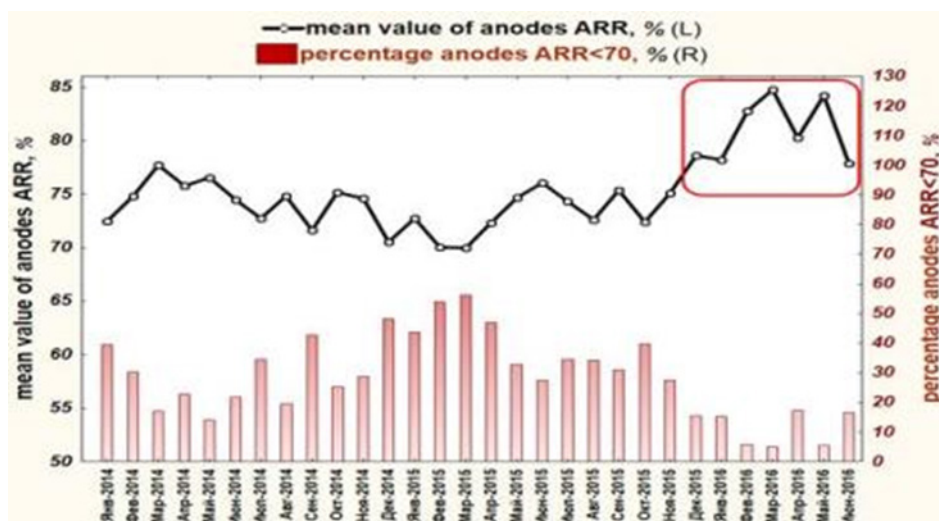


Figure 10. Variation of ARR of prebaked anodes.

5. Ways Forward to Enhance Productivity

The next step to enhance the efficiency was the decision to test anodes with chamfered edges to reduce the weight of the block and to decrease anode consumption. Different versions were considered (Figure 11):

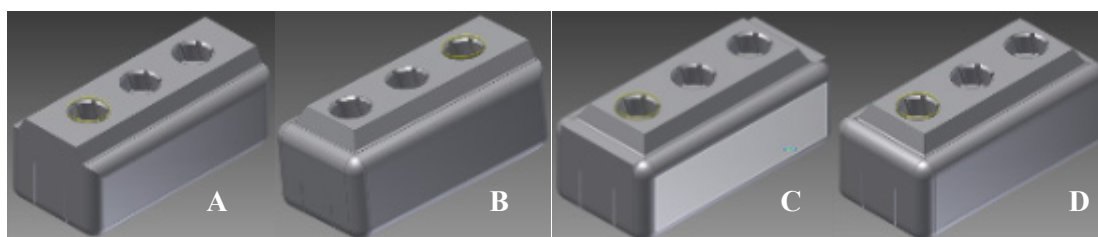


Figure 11. Anode versions with chamfered edges.

For industrial tests we chose “D” type anode – this is the shape of the new optimized anode with chamfered edges (Figure 12). Industrial tests were carried out in three smelters: Sayanogorsk, Krasnoyarsk and Irkutsk, on different cell types. Performance of the anodes was evaluated for three months. The tests showed that the butts are of regular geometric shape, no burn off at the end and side parts of the butt were observed, reduction of prebaked anode consumption was from 4 to 22 kg/t Al, this makes possible to reduce costs on the average by 6.5 \$/ t Al . Test results made possible to recommend implementation of the anode.



Figure 12. New optimized anode with chamfered edges.

6. Conclusions

Comprehensive work on mathematical modeling and industrial tests made possible to choose and assess performance of the prebaked anode of new design. Optimization of geometric dimensions of the anode, depth of the stub hole and shape of faces made possible to improve efficiency of aluminum production:

- Reduce prebaked anode consumption by 5 - 7.5 kgC/t Al and electric energy consumption by 85 to 290 kWh/t Al (depending on the cell type),
- Improve quality of produced prebaked anodes: CRR up to 92.2 %, ARR up to 81.3 %.

7. References

1. Werner K. Fischer, Felix Keller, Raymond C. Perruchoud, Interdependence between anode net consumption and pot design, pot operating parameters and anode properties, *Light Metals* 1991, 681-686.
2. R&D Carbon Ltd, Testing equipment, Light Metals Ltd., exclusive representative of R&D Carbon in Russia, 2013.
3. Markus Meier, Carbon consumption and ways to its reduction, R&D Carbon Ltd., *Congress Non-Ferrous Metals Krasnoyarsk*, 2012.
4. G. Ye.Volfson, V.P. Lankin, Production of aluminum in cells with prebaked anodes. – *Metallurgiya*, Moscow, 1974.
5. E.A.Yanko, Anodes of aluminum cells, *Ruda i Metally*, 2001.
6. Markus Meier and Raymond Perruchoud, Anode performance and influence on smelter cost, R&D Carbon Ltd, *VII Intl. Congress & Exhibition - Non-Ferrous Metals and Minerals*, Krasnoyarsk, Russia, 2015.

