

Strategy for sustaining anode quality amidst deteriorating coke quality

Tapan K. Sahu¹, Saleh Ahmed Rabbaa², Amer Al Marzooqi³, Muhammad Shafiq Malik⁴, Bienvenu Ndjom⁵, Pragasan Palavar⁵ and Esam Mohamed⁶

1. Manager, Process Control & Improvement, Carbon and Port; 2. Vice President, Carbon and Port;
3. Senior Manager, Paste Plant & Baking Kilns, Carbon and Port; 4. Manager, Paste Plant, Carbon and Port;
5. Lead Engineer, Process Control, Carbon and Port; 6. Manager, Raw Materials, Strategic Sourcing
Emirates Global Aluminium (EGA), Jebel Ali (DUBAL), Dubai, UAE
Corresponding author: tksahu@ega.ae

Abstract

The gradual deterioration in anode grade coke quality over the past two decades and its impact on anode quality has been well documented [1, 5] by coke suppliers and anode producers alike. EGA Jebel Ali (also known as Dubai Aluminium PJSC or DUBAL) also experienced the challenge of decline in vibrated bulk density (VBD) and increased impurity levels in coke. To minimize the impact of these variables on anode quality, DUBAL devised a strategy to blend different coke types; and adapt its anode manufacturing process, which yielded an increase in baked anode density of more than 0.015 g/cm³ without compromising other key anode properties. As a part of its long-term business strategy to secure its own raw material, DUBAL entered into a joint venture with Chinese coke producer Sinoway Carbon Energy Holdings (Sinoway) in Shandong. This paper describes DUBAL's strategy for the blending of shaft and rotary calcined coke at DUBAL, process adaptations at Carbon Plant and the joint work done with Sinoway to optimize the calcining process, thereby improving key coke properties such as - VBD, coke reactivity and particle sizing - which resulted in improved anode quality and performance.

Keywords: Shaft calcined coke; vibrated bulk density; coke blending; baked anode density; Blaine Index.

1. Introduction

Consistent high quality anodes are a basic requirement of any high performance smelter. Anode quality is influenced by several key factors, including raw materials properties and the anode formulation process. Calcined petroleum coke (CPC) is a key raw material used in the production of anodes for the aluminium industry, representing approximately 65 % of the anode weight. The quality of CPC has gradually declined over the past two decades. Presently, deterioration in raw material properties (CPC and coal tar pitch) is considered to be one of the most significant challenges in the anode manufacturing industry, as it adversely affects anode quality and performance.

DUBAL has traditionally sourced CPC from US Gulf Coast producers. As the demand for CPC grew in the late 1990s and CPC production in the Middle East and Asia became prevalent, economics and logistics favoured the procurement of CPC from these sources. For economic reasons and security of operations, DUBAL sourced CPC from multiple suppliers. Exposure to CPC from a multitude of geographic locations provided valuable insight into its unique characteristics.

It was observed that the general increase in the quantity of heavy sour crudes processed by the petroleum industry in the past decade resulted in an increase in metallic impurities and a decrease in VBD, both of which were detrimental for anode performance and aluminium purity. Since DUBAL used CPC from individual suppliers on a campaign basis (prior to blending until 2008), the properties of the anodes that were produced with these cokes became more

pronounced due to variations in coke quality from different suppliers (Figure 2). This made optimising anode usage in the reduction cells more challenging. In particular, step-changes in baked anode density and reactivity were observed. DUBAL's aging Paste Plants were operating beyond their design capacity; so the issue of increasing the density of anodes while using lower VBD coke for production, could not be addressed by process adjustments alone.

This paper explains DUBAL's journey to sustain and further improve the anode quality in spite of the deteriorating coke quality. Figure 1 outlines the long-term strategy applied by DUBAL in various stages to overcome the market challenges for coke quality and prepare for future challenges.

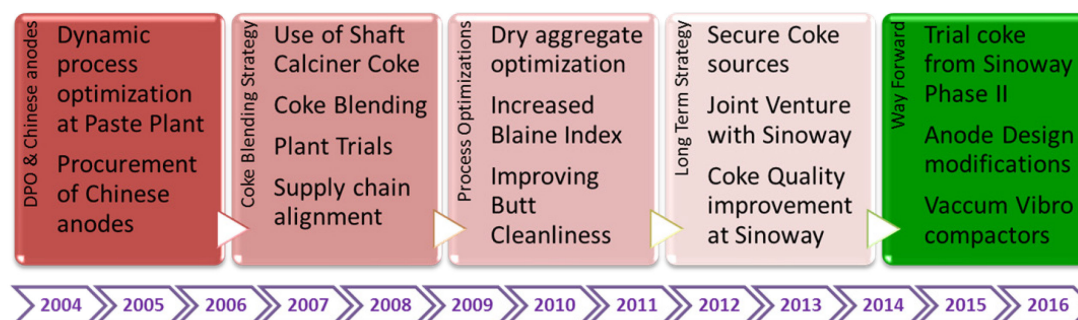


Figure 1. DUBAL Strategy to address deteriorating coke quality.

2. Deterioration in coke quality before coke blending at DUBAL (2000 to 2008)

DUBAL, like many western smelters, has sourced the majority of its CPC requirements from producers using rotary kiln technology. The gradual deterioration in aluminium grade green petroleum coke (GPC) made it extremely challenging for CPC producers to meet smelter specifications. As a result, the quality of coke used at DUBAL shifted towards lower vibrated bulk density (VBD) and higher impurity content – mainly vanadium (V), nickel (Ni) and sulphur (S) (Figure 2). From 2000 to 2008, V levels in calcined coke increased on average by 23 % (48 ppm), while the concentrations of Ni and S increased by 33 % (38 ppm) and 14 % (0.3 % abs.) respectively. Coke VBD also dropped on an average by 0.02 g/cm³ with minimum of 0.87 g/cm³ from a few suppliers, due to the higher volatile matter content of processed green cokes.

The impact of increased chemical content of coke is well known to the anode manufacturing process experts. V is a known catalyst for the reaction of carbon with oxygen at elevated temperatures. As V and Ni levels increase, there is a rise in excess carbon consumption because of air burning of anodes, which can negatively affect cell stability. Likewise, calcium (Ca), silicon (Si), sodium (Na) and iron (Fe) are also undesirable impurities in coke. Calcium can have a significant negative effect on coke and anode CO₂ reactivity, and therefore needs to be controlled; while sulphur represents an environmental constraint to meet the permitted limits for SO₂ emissions, which is not an immediate threat for DUBAL.

Another important aspect is that DUBAL operates six different cell technologies, with the oldest technology being more than 30 years old. Modern electrolysis cells such as DX cells (DUBAL technology) with deep cavity designs are not as susceptible to anode air burn as the oldest cell design (D18). This is because the ability to cover anodes and maintain cover levels is significantly better in DX cells than older cell designs, where the anodes sit higher in the cell cavity. Thus, more reactive anodes are likely to cause variations in butt thickness for older DUBAL technologies. Higher variation in butt thickness increases the Fe contamination in the metal. Greater amounts of carbon dust from more reactive anodes also increases the percentage of "hot" pots, which ultimately increases the proportion of Fe and Si in the metal. Therefore, anode air reactivity is a concern for DUBAL anodes that are used in older cell designs.

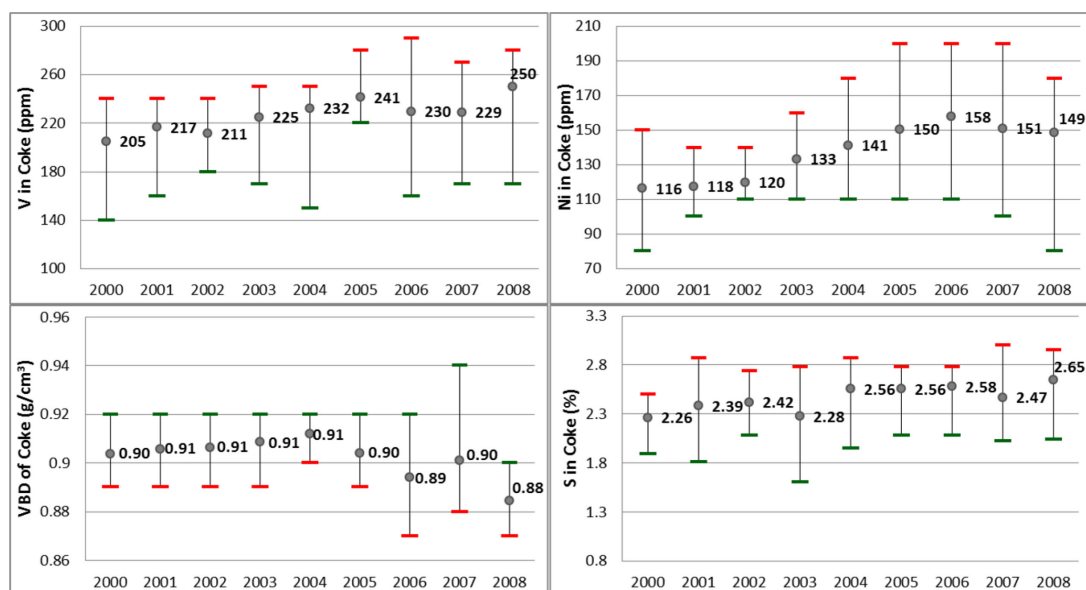


Figure 2. Variation in coke quality before coke blending at DUBAL (2000-2008).

3. Process adaptations

Besides the coke quality changes, capacity creep through amperage increase has been a constant process at DUBAL (plant amperage increased from 192 kA in 2000 to 242 kA in 2015 year-to-date (YTD)). Henceforth in this paper, 2015 YTD refers to the aggregated value until August 2015. The following section provides detail on how DUBAL has successfully adapted to these challenges through incremental improvements in the Paste Plant and other parts of the smelter (butt cleanliness, fire cycle optimisation in Baking Kilns, etc.)

3.1. Dynamic process optimisation (DPO) at Paste Plant

To explore the capability of the existing plant and to cater for raw material deterioration, DUBAL embarked on an anode quality improvement programme in 2005, with R&D Carbon using DPO as a tool. The anode recipe was modified with finer fines (Blaine Index (BI) of 4000) and the preheating, mixing and forming process parameters were optimised. A mobile pilot press was used to prepare pilot samples for evaluating the impact of the changes during the optimisation process. Following positive laboratory results, changes were implemented in full production. The knowledge gained from the pitch optimisation trial helped to reduce the pitch content in anodes by 0.7 % without compromising the anode quality; and increased throughput by 6 % (i.e. 33 t/h to 35 t/h in both production lines) over the nominal level without any plant modifications. This programme also guided increased throughput of both green anode manufacturing lines by 3 % (35 t/h to 36 t/h both production lines) after two-and-half years, through minor plant modifications [2].

After the second stage of throughput increase, the BI could not be sustained due to insufficient ball mill capacity, so the target BI was decreased to 3700.

3.2. Understanding the behavior of Chinese cokes while using Chinese anodes

Despite increased anode throughput, subsequent amperage increases resulted in smelter anode demand outstripping anode supply from DUBAL's Carbon Plant. The shortfall was procured

from third parties, primarily from China. These anodes were produced with 100 % Chinese coke, produced by vertical shaft calciners.

This presented an opportunity to understand the characteristics of Chinese cokes. Figure 3 illustrates the variations associated with anodes received from different suppliers. The anodes received from some suppliers had higher air reactivity residue (ARR) and carboxy reactivity residue (CRR), which could be largely attributed to the selection of GPCs that are blended to produce the CPC. Chinese anode plants generally had their own calcination units to produce CPC for their anode production. On site process audits of these plants provided invaluable opportunities to develop a good understanding of the quality variations and behaviour of different GPCs distributed across China. Also, a better process understanding was developed with respect to the shaft calcining process and the coke characteristics. This prompted DUBAL to consider blending with higher VBD shaft calciner cokes as an option to improve anode density.

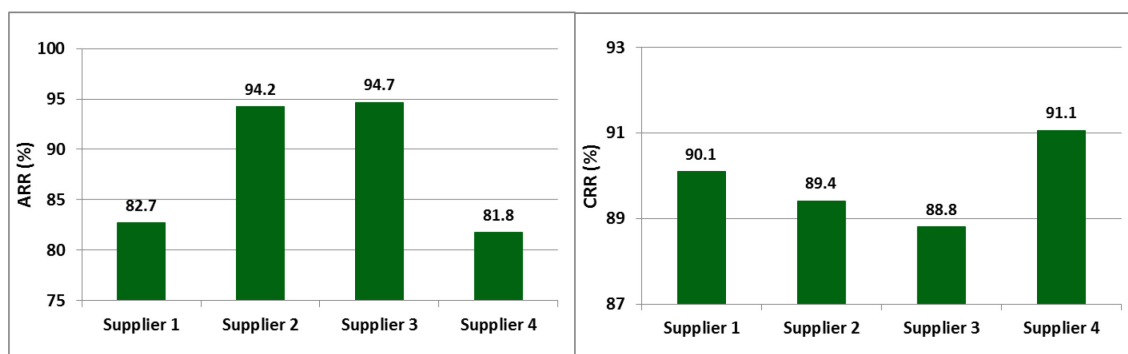


Figure 3. Air reactivity residue (ARR) and carboxy reactivity residue (CRR) of Chinese anodes used at DUBAL.

3.3. Coke blending strategy

The main aim of coke blending at DUBAL was anode density improvement, with minimal impact on anode reactivity. Our vast experience with Chinese anodes, combined with the abundant availability and favourable landed cost of shaft calcined coke, made it the most favourable option as an anode density enhancer. The challenge for DUBAL was to identify suitable rotary kiln cokes, which when blended with shaft calcined coke, would negate some of its weakness i.e. high reactivity.

The strategy that DUBAL adopted for coke blending was as follows:

1. Develop a system for ranking cokes used at DUBAL and expected future coke sources according to their intrinsic properties as well as the properties of the anodes that they produced.
2. Produce pilot scale anodes with different blend ratios.
3. Conduct extensive analysis of pilot anodes to determine which blend ratio(s) are most beneficial for improving anode quality.
4. Follow-up the pilot scale trial with a plant scale trial.
5. Conduct extensive analysis of plant trial anodes to confirm the results of the pilot scale trial.
6. Supply anodes to a selected group of trial pots and monitor pot performance and butt parameters.
7. Adjust coke procurement plan and delivery schedule.
8. Full plant scale implementation.

3.3.1. Pilot test results

Pilot tests were conducted in 2009 by external technical laboratories, with the objective to assess the potential gain in density by the use of shaft calcined coke and the expected trade-off in reactivity. Four different sources of CPC were tested: two regular supply and two new sources. Optimum baked anode density with maximum reactivity residue was achieved with the blend consisting of 33 % to 67 % of shaft calcined coke.

3.3.2. Plant trial results

A plant scale trial was conducted where trial anodes were produced and analysed extensively before they were supplied in a controlled manner to a small group of pots. The results from the analysis of the trial anodes correlated well with the results from the pilot test. Optimum baked anode density and maximum reactivity residue were achieved when high density coke was blended with low density coke in a ratio ranging from 25 % to 50 %. With the confidence gained from the bench scale and plant trials, the full implementation of coke blending was decided and blending ratios were defined.

3.3.3. Full-scale implementation of coke blending

As a long-term solution, a Coke Blending Facility was installed in the Port area at DUBAL. All coke silos were equipped to adjust their rate of coke extraction automatically, according to a predefined blending target. Coke from the various silos is discharged onto a common conveyor belt, which deposits into a buffer hopper. Road tankers then transfer the blended coke to the smaller silos at the Paste Plant for anode production. Multiple transfer points assist in thoroughly mixing the constituent cokes.

An evaluation of the impact of coke blending over a six-month period showed an overall increase in baked anode density of 0.01 g/cm^3 [3] (Figure 5) and minimal variation in anode reactivity. This benefit was preserved over the long-term (Figure 10) irrespective of the variation in coke VBD (Figure 4).

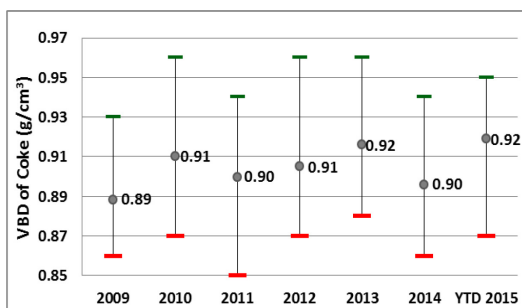


Figure 4. Baked anode density improvement during plant trial.

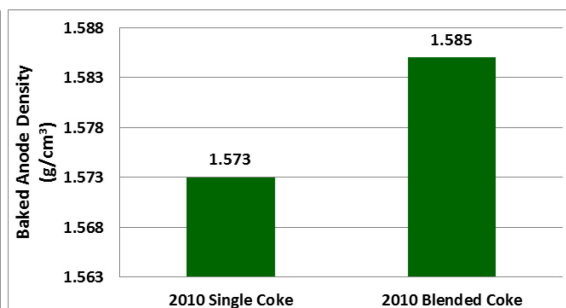


Figure 5. Range of VBD for individual cokes.

3.3.4. Strategic alignment with supply chain and port

To ensure the continuity of blending ratios as per the production plan for desired anode density, it was crucial to receive the right type of cokes at the right time and of the right quality as well as the right quantity in the Paste Plant. The DUBAL Port and Supply Chain teams played a critical role in this process. The procurement plan was developed as per the blending requirements; and shipping schedules were managed and adjusted to minimise the risks to DUBAL. The coke storage in silos at the Port was also planned in advance so that the right proportions were blended before transporting the material to the Paste Plant.

3.4. Process optimisation at paste plant

3.4.1. Dry aggregate optimisation (Increased +4 mesh particles):

DUBAL's dry aggregate comprised three size fractions: coarse, medium and fines. The coarse fraction is composed of recycled butts material, while the other two fractions are primarily made up of CPC. Grain size distribution (or dry aggregate curve) is a critical parameter for anode quality.

Several trials were conducted to evaluate the impact of increasing the amount of +4 mesh particles in the recipe and to determine the optimum percentage. Positive results from trials led to the replacement of screens to increase the proportion of +4 mesh particles in the dry aggregate from 22.5 % to 25.5 %. Baked anode density increased by 0.01 g/cm³ with an associated decrease of 0.3 nPerm in air permeability [3].

3.4.2. Increased Blaine Index (BI)

In a rotary kiln, most of the fine green coke (< 250 µm) is blown out from the back of the kiln with the flue gas. In a shaft calciner, there is no mechanism to remove fine green coke and it stays with the product. The fine coke attaches to the surface of the coarser particles and is easily abraded when the coke is handled and dust is generated. Hence, shaft calcined coke has relatively high levels of - 75 µm fines. DUBAL became aware of this phenomenon when the Operations team complained about excessive dust generation while handling the initial consignments of shaft calcined coke. The flipside of this nuisance was an increase in the rate of production and BI of ball mill fines.

The benefit of increasing the "fineness" of the anode recipe was already well understood at DUBAL. However, previous attempts to increase the "fineness" of ball mill fines were not sustainable since the ball mill capacity did not permit the increased throughput without compromising BI.

In 2013, after gathering sufficient data on variation in fines production rate and BI, while operating with varying ratios of shaft calcined coke in the coke blend, the BI target was increased (Figure 6). Consequently, baked anode density increased and air permeability decreased.

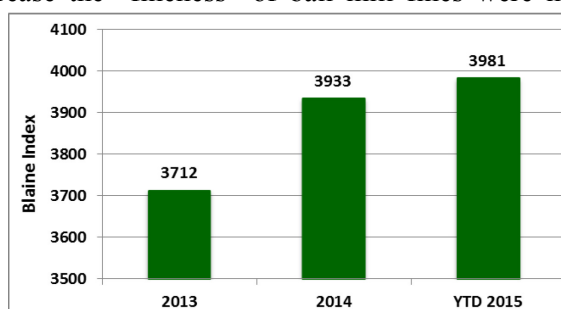


Figure 6. Increase in Blaine Index target.

3.5. Improved Butts Cleanliness

Anode properties such as density and reactivity are also influenced by the butts quality, and therefore butts cleanliness is one of the critical parameters monitored at DUBAL. Butts undergo a three-stage cleaning process to ensure effective cleaning. The efficiency of the butts cleaning machine was improved and an online 3D butt analyser was installed for 100 % monitoring of butts. The butt analyser at DUBAL measures all butt dimensions and butt surface area with bath, and is equipped with a locally displayed visual summary of butt cleanliness (Figure 7) for re-cleaning of butts that do not achieve the desired level of cleanliness. As a result, butt cleanliness improved and the Na level in anodes dropped to approximately 150 ppm (Figure 8).

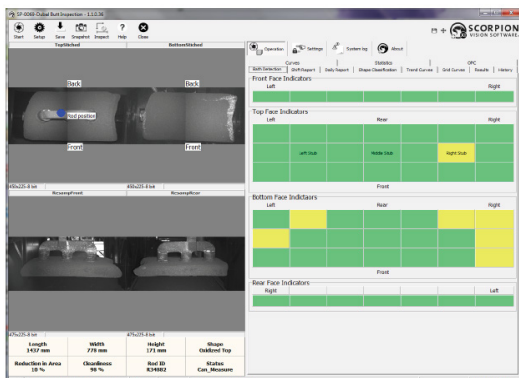


Figure 7. Butt analyser - cleanliness dashboard.

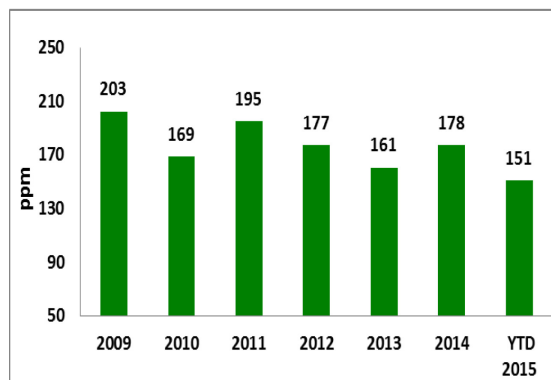


Figure 8. Sodium in anodes.

3.6. Anode baking process optimisation for using shaft calciner coke

Smelters generally tend to use real density (RD) or, in the case of DUBAL, crystallite size (Lc) as an indication of anode baking level and coke calcination level. For optimum anode reactivity and performance, a difference of 0.2 nm (nanometers) between anode Lc and coke Lc is preferred [6].

The shaft calciner cokes received at DUBAL tended to have higher calcination levels than rotary kiln cokes. Unless actioned, the difference between anode and coke Lc may diminish, thereby resulting in dusting issues in the potrooms. To avoid such problems, DUBAL had to increase the anode baking level by careful adjustment of soaking temperature and preheating parameters in accordance with the higher calcination level of the shaft calciner cokes [8].

3.7. Long-term strategy to secure coke requirement

DUBAL procures approximately 320 000 tonnes of coke annually from multiple suppliers, accounting for approximately 10 % of the total cost of aluminium production. To minimise the risk of raw materials availability, DUBAL took a strategic decision to secure a significant portion of its coke requirement by investing in upstream production capacity.

Given that China was the largest producer of anode grade coking products worldwide and possesses approximately 40 % of the world's GPC, a major raw material for CPC, investing in CPC production in China was a sound choice. Therefore, EGA entered into joint ventures with two Chinese coke producers, namely, Jiangsu Tancai Company Limited (Suyadi) in Zhenjiang and Sinoway Carbon Energy Holdings (Sinoway) in Shandong. Suyadi coke was used exclusively at EGA Al Taweelah (also known as Emirates Aluminium or EMAL) while Sinoway coke was primarily used at DUBAL. The Sinoway calciner has an annual capacity of 280 000 t/year (Phase I). The calciner is not only equipped with reliable production facilities but is also operated with established environmentally-friendly process technology resulting in stable performance supported with well managed operations. Sinoway would eventually become the

major supplier of high density coke to DUBAL representing more than 50 % of DUBAL's total coke consumption.

3.7.1. Process improvements with Sinoway to produce best suitable coke for DUBAL

The first trial consignment of Sinoway coke was received at DUBAL in 2013(Q4). Based on the experience of trial coke from Sinoway, and its comparison with other Chinese coke used in the past, it was observed that the coke quality could be further improved. Since DUBAL was a major consumer of the CPC from the venture with Sinoway, it could play a critical role in influencing the quality and consistency of its CPC. To that end, DUBAL and Sinoway jointly devised a quality plan that included regular audits by DUBAL personnel, highlighting product quality concerns and identifying options for process improvements. The outcome of the process audits was the opportunity to improve coke reactivity while increasing VBD, improve blending accuracy, reduce dust generation during coke handling, and decrease the quantity of the coarse coke in the granulometry.

In 2014, this approach resulted in changes to plant equipment, upgraded laboratory facilities, revised selection of GPC and process adjustments that together led to improvements in overall coke quality. The CO₂ reactivity of coke decreased by 4 % (abs) and the coke VBD improved by 0.03 g/cm³ (Figure 9).

Developing a thorough understanding of the coke calcining process and working closely with the calciner to highlight the implications of particular coke properties on smelter operation has been fundamental to improving and sustaining the quality of coke that DUBAL received from Sinoway over the last year.

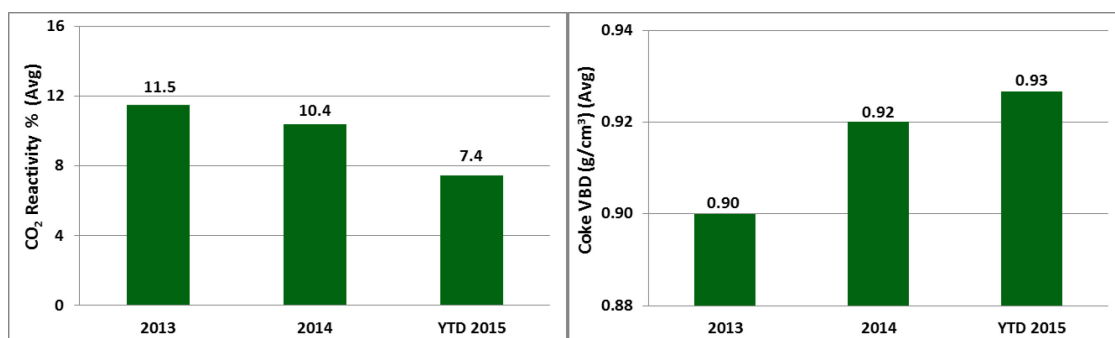


Figure 9. CO₂ Reactivity and VBD of Sinoway coke.

4. Results

4.1. Improved anode quality

Since 2005, multiple actions have been taken to improve anode density and sustain anode reactivity. As a result of coke blending and process adaptations, significant improvements in both anode density and anode impurity levels were observed in spite of deteriorating coke quality from various suppliers. These improvements were sustained (Figure 10) even though the smelter continued to increase its metal production capacity.

- Baked anode density increased by more than 0.015 g/cm³ without compromising other anode properties. The results from 2012 onwards show a slight decrease in density (Figure 10). This was partly attributed to the gradual reduction in the percentage of butts in anode (from 26 % to 23 %), in line with the improvement of both GCC and NCC (Figure 11).

In 2014, a drop of 0.005 g/cm³ was observed while optimizing the process parameters for Sinoway coke, but the drop was recovered with improvements in Sinoway Coke Quality.

- ARR and CRR had declined until coke blending was introduced. However, the decline was arrested from 2010 onwards and was maintained at satisfactory levels of 75 % and 94 % respectively by reducing the impurity levels (e.g. V) in blended coke. Air reactivity is improving in 2015 due to the improved quality of Sinoway coke and butt cleanliness.

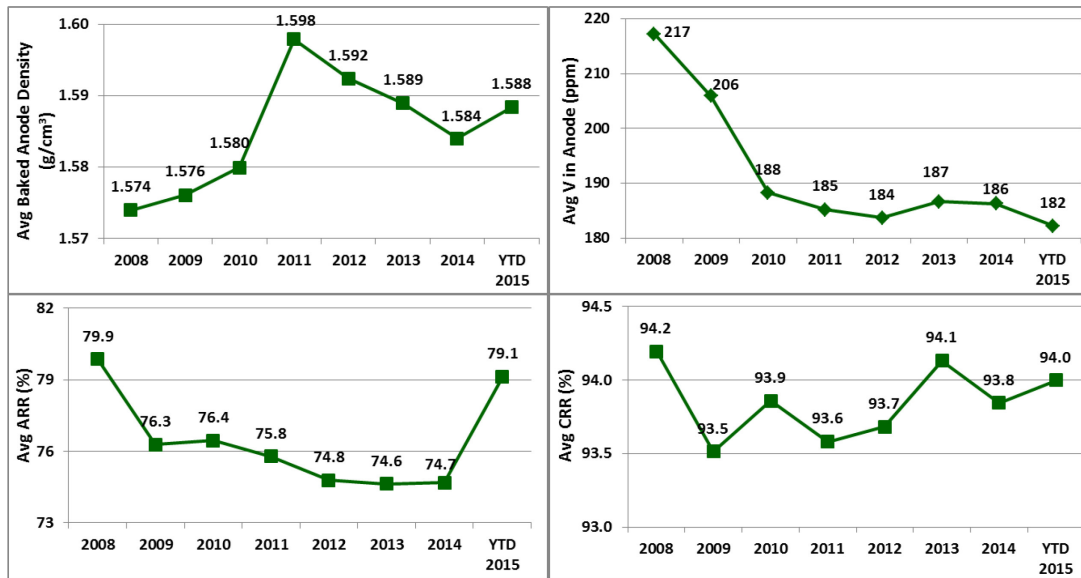


Figure 10. Anode quality trend 2008 to 2015 (YTD).

4.2. Improved smelter performance

The strategy to improve the anode quality amidst deteriorating coke quality contributed to the improved anode performance [4,8] results (as illustrated in Figure 11), through the smelter process optimisation.

- Reduction in Gross Carbon Consumption by 4.6 %;
- Reduction in Net Carbon Consumption by 3.9 %.

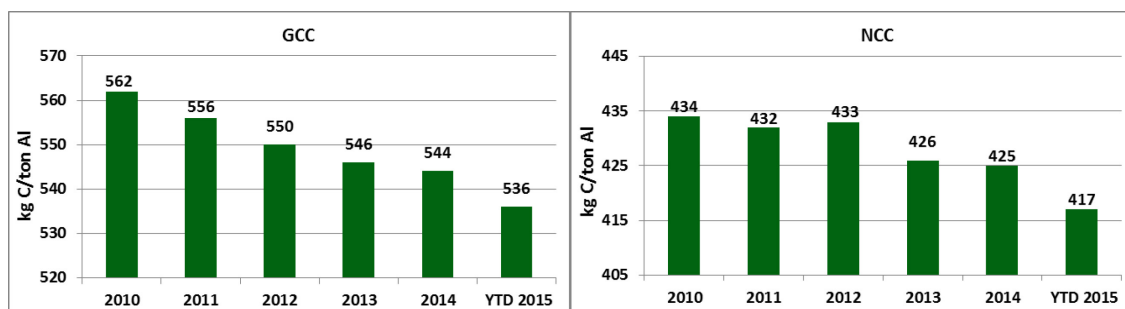


Figure 11. Gross Carbon Consumption (GCC) and Net Carbon Consumption (NCC) 2010 - 2015 YTD.

Figure 11 represents the average values for the entire smelter (all cell technologies). The cells operating with DUBAL's latest technology (DX+ Ultra) have GCC of 525 kg C/tonne Al and NCC of 408 kg C/tonne Al (YTD 2015).

5. Conclusion

DUBAL Carbon Plant has adapted well to the changing requirements of the smelter by ensuring that continuous improvements in anode quality were realised.

Synergistic blending of cokes at DUBAL has proven to be an effective strategy to address the deterioration in coke quality. Thorough understanding of the strengths and weaknesses of individual cokes and a well-aligned supply chain have been fundamental to successful coke blending.

As bulk densities of rotary kiln cokes continue to decrease, shaft calciners provide a viable source of high density coke that can be used to sustain anode density. DUBAL has applied an effective long-term strategy by securing more than 50 % of its coke requirements through a joint venture with Sinoway, with the added flexibility to customise the coke calcining process in order to meet DUBAL's process requirements. This approach was pivotal in addressing the high CO₂ reactivity, which seemed typical of Chinese cokes, through the proper selection of GPCs and subsequent process changes.

Sinoway is expected to increase its production capacity by 350 000 t/year in 2016 (Phase II); and would use its patented calcination technology to produce low sulphur CPC from high sulphur GPC at competitive cost and without any adverse impact on environment. A trial consignment of this coke will be tested at DUBAL to establish the process advantages.

To further improve anode performance and provide greater flexibility for processing cokes with varying VBD, DUBAL plans to install vacuum vibration systems in both paste plants. Cutting of length-wise slots, anode top profile modification and anode length increases will also be introduced shortly to further improve anode performance and generate energy savings.

6. References

1. L.C. Edwards, Responding to Changes in Coke Quality, Proceedings of the 9th Australian Smelting Technology Conference, Terrigal, NSW, Nov 2007.
2. R. Akhtar, S Rabba, M Meier, "Dynamic process optimization in paste plant", Light Metals, 2006, pp 571-575.
3. Bienvenu Ndjom et al, "Improving Anode Baked Density and Air Permeability through Process Optimization and Coke Blending", Light Metals 2013, pp 1105-1110.
4. Edouard G. M. Mofor et al, "Optimising Anode Performance in DUBAL Reduction Cells", Light Metals 2014, pp 1199-1202.
5. Franz Vogt, Robert Tonti, Maia Hunt, Les Edwards, "A preview of Anode Coke Quality in 2007", Light Metals 2004, pp 489 – 493.
6. Khalil Khaji and Hameed Abbas, "Baked anode Density Improvement through Optimization of Green anode Dry Aggregate Composition" Light Metals 2010, pp 1027-1030.
7. L.C. Edwards, F Vogt and J Wilson, "Coke Blending at Anglesey Aluminium", Light Metals 2001, pp 689-694.
8. Tapan K. Sahu et al, "Improving Anode Performance Through Anode Quality Improvement at DUBAL Carbon Plant", 11th Australasian Aluminium Smelting Technology Conference, Dubai, 6 – 11 December, 2014, Paper 06M4.