VOTORANTIM METAIS/CBA BAUXITE RESIDUE: CHALLENGES AND SOLUTIONS

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ABSTRACT

Bauxite residue is a worldwide challenge for alumina refineries. Economic disposal for new deposits, lifetime increase of the existing ones, as well as the utilization of bauxite residue as raw material in other industries, even after more than 100 years of Bayer process existence, is still an ongoing process and no economically viable solution has been developed yet. Votorantim Metais/CBA wet disposal bauxite residue disposal area lifetime ends in 2019 and there is no possibility for expansion. To avoid a new dam construction, a study was developed to evaluate the possibility of changing the disposal method and its benefits. The installation of press filters using the existing dam presented the best performance, increasing the bauxite residue disposal lifetime by until 2050. In parallel, in cooperation with Votorantim Cimentos, a technology to process and use up to 30% of bauxite residue as raw material in the cement production was developed. Good quality cement was produced and the developed technology showed economic benefits for both Votorantim Cimentos and Votorantim Metais.

1. INTRODUCTION

Bayer Process dissolves gibbsite present in Bauxite (aluminum ore) with hot caustic soda to produce aluminum oxide. Remaining insoluble residue is separated by settling and filtration. After residue washing for alumina and caustic recovery, the washed residue is transferred to the disposal area. Companhia Brasileira de Alumínio (CBA) produces 420 ktpy of aluminum, generating about 600 ktpy of bauxite residue. This residue is pumped to a disposal area (dam), named Palmital, with remaining disposal capacity until 2019. Currently, disposal area (Figure 1) contains about 2 million cubic meters of supernatant water. This study is to evaluate alternatives to increase the bauxite residue dam capacity and develop technology to make possible the use of bauxite residue in the cement production.

Figure 1 - Cia. Brasileira de Alumínio Dam (Palmital)

2. CONCEPT STUDY

Bauxite residue disposal area was raised to its final elevation in 2008 and will have exhausted its useful volume, 30 million cubic meters, in 2023. The principal dam is 1.000 meters long and 102 meters high. The construction of a new disposal area will require a high investment and due to the local topography has to be constructed far from the refinery. Obtaining necessary environmental licenses for a new disposal area will also present a range of challenges.

In face of this scenario, a study was conducted in 2012 to identify and evaluate alternatives to increase the lifetime of the existing disposal area by means of changing the disposal method.

Disposal Method	Volume of deposited residue (m3 / year)	Lifetime (year)	Date of end lifetime Ref. Jan/2012
* Wet Disposal	1.347.782	7.5	June/2019
"Dry Stacking"	1.013.493	8.6	July/2020
"Dry Disposal"	748.870	38.2	Setember / 2050

Table 1 – Disposal Method Comparison

"Dry Stacking" (60% of solid content) and "Dry Disposal" (75% solid content) were the alternative disposal methods considered in this study. Comparing different methods to the current CBA wet disposal method, Dry

Disposal provided the longest disposal area lifetime (Table 1).

2.1. Dry Disposal

"Dry Disposal" consists of the deposition, spreading and compaction of the residue with earthmoving equipment. To make this possible, it is necessary to dewater the residue before the disposal until a solid content in the range of 75% to 80%. Press filter technology is applied to achieve this range of solids content (Nery, 2014).

2.1.1. Press Filter Pilot Test

A pilot test using a Filter Press (Figure 2) was performed to evaluate the performance of the equipment and its specifications to design the full scale facility and produce bauxite residue for geotechnical evaluation (Figure 3). The filter press was fed with a suspension of bauxite residue with 45% of solid content and 8,500 kg of residue with 75% of solid content were produced.

Figure 2 – Pilot Test Press Filter

Figure 3 – Press Filter Bauxite Residue Cake

The pilot test confirmed the volume reduction of 40% in the bauxite residue and showed a caustic soda and alumina recovery of 92%. A visual comparison between wet disposal bauxite residue and press filter cake can be seen in Figure 4.

Figure 4 - Wet and Press Filtered Residue

2.1.2. Disposal Test

Using the Press Filtered Residue generated by the pilot equipment deposition, spreading and compaction process were simulated. An area inside the dam surrounding the already disposed residue was prepared and a test was performed to determine the angle of repose, stacking density, ease of handling and geotechnical characterization (Figures 6 to 10).

Figure 5 – Prepared Area

Figure 6 – Stacking

Figure 7 – Angle of Repose Test.

Compaction testing was performed using a ditch filled with bauxite residue from the pilot plant and passing an excavator twelve times over it. The results showed a compaction of 99% and 35^o angle of repose.

Figure 8 – Spreading Test.

Figure 9 – Compaction.

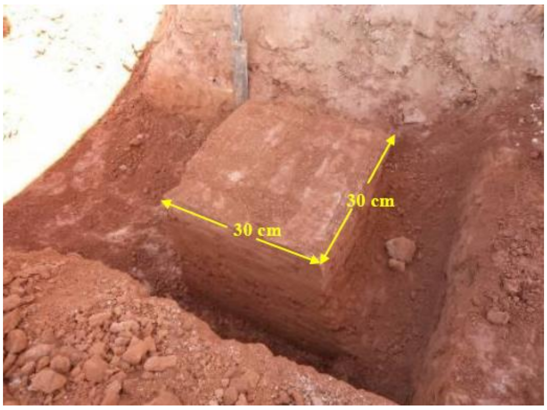

Figure 10 – Compacted Sample

2.1.3. Palmital Geotechnical Evaluation

A key point to change the Palmital disposal method is the behavior of the existing residue when covered by the Press Filtered Residue.

Geotechnical evaluation was performed to evaluate the existing residue properties and determine the capacity to support the Press Filtered Residue (Figure 11).

Figure 11 – Geotechnical sampling

Particle Size, CPTu (Cone Penetration Test), PPDT (Pore Pressure Dissipation Test), VT (Vane Test), SPT (Standard Penetration Test), Shelby and many other analyzes were performed in different points inside the dam to guarantee the stability of the system.

2.2. Bauxite Residue Disposal Project

Using the geotechnical parameters, a new design of the bauxite residue disposal area (Figure 12) was developed to utilise all of the available area. This project will increase the Palmital lifetime, allowing continued disposal through until 2050 and increase the recovering of caustic and alumina from

bauxite residue, saving US$ 10 million per year and postponing for 31 years the investment in building a new disposal area.

To achieve this goal the following steps have to be considered (Nery, 2014):

- 1st STEP: Construction of an initial landfill over natural ground in the left and right edges of the reservoir (Figure 12).

- 2nd STEP: Dry disposal (forming a stack) of the residue from press filter over the initial landfill (Figure 13).

- 3rd STEP: Dry disposal (forming a stack) of the residue from press filter within the reservoir (Figure 14).

- 4th STEP: Dry disposal (forming a stack) of the residue from press filter over the stack formed in the 2nd step, with final crowning at the final elevation of the basin (Figure 14).

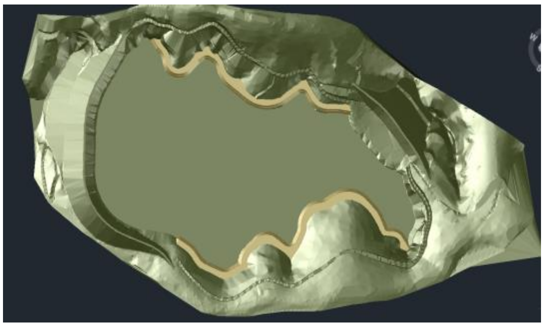

Figure 12 – 1st Step

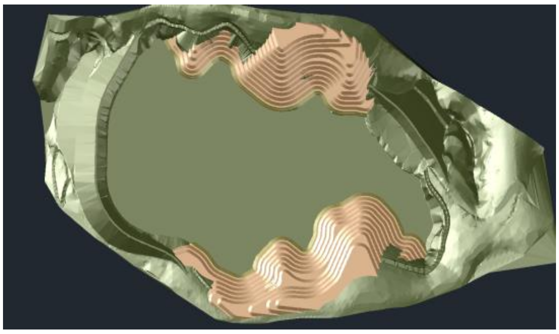

Figure 13 – 2nd Step

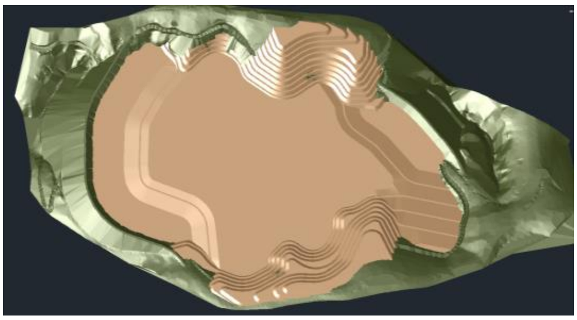

Figure 14 – 3th and 4th Step

3. PALMITAL PREPARATION

Before starting the Press Filter operation, the Palmital area needs to be prepared.

A bathymetry survey conducted in 2012 indicated the existence of 2 million m³ of supernatant water. At least, 75% of this water will need to be removed from the surface to enable the disposal of press filtered bauxite residue over the existing residue.

3.1. Palmital Water

Palmital water characterization showed low concentration (0.4 to 0.6 g/L) of sodium fluoride, sodium chloride, sodium sulphate and sodium oxalate. The water also contains 30 g/l of Total Alkalinity (TA), 12 g/L of Total Caustic, both expressed as Na_2CO_3, and 8 g/L of Al_2O_3. The total amount of caustic and alumina contained in Palmital supernatant water worth US$ 25 million.

3.1.1. Use of Palmital Water in the Alumina Refinery

Palmital water can be removed from the lake and used in the refinery. Some options to use this water in the alumina production process were identified. The best alternatives were a) replace the condensate and industrial water used in the lime hydration processes; b) replace the industrial water used in the flocculant dilution process; c) replace the industrial water used in the refinery red side gaskets.

3.1.1.1. Water in Flocculant Preparation

In order to verify the impact of using Palmital water in the flocculant dilution process, tests were performed replacing the industrial water by Palmital water and the solid sedimentation rate was compared. The preparation of the flocculant is made in two-step dilutions. First, the flocculant is diluted to 1% than a second dilution to 0.3%. Figure 15 shows a significant improvement of the residue settling rate when industrial water is used in the first dilution and Palmital water in the second dilution. These figures validate the replacement of industrial water by Palmital water in the second dilution besides an improvement in the flocculant effectiveness.

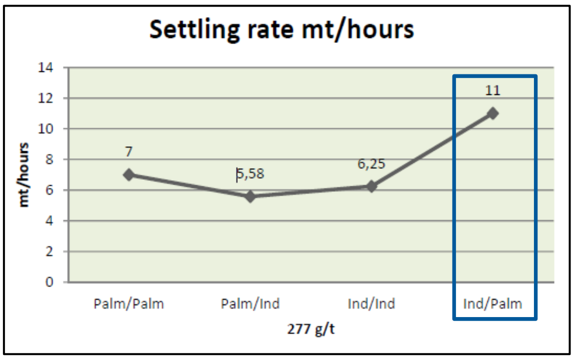

Figure 15 - Settling Rate

3.1.1.2. Water Use in Lime Hydration

Lime hydration process was conducted in the refinery mixing condensate and industrial water to achieve a controlled temperature. A plate heat exchanger was installed to heat Palmital water using live steam (Figure 16) to the desire temperature. It allowed the replacement of 100% of condensate and industrial water by Palmital water.

Figure 16 – Plate Heater

3.1.1.3. Gasket Water

Industrial water used in the refinery red side gaskets could be replaced by Palmital water. To avoid problems with solids present in the water a security filter was installed (Figure 17).

Figure 17 – Palmital Water Security Filter

3.2. Palmital Conquest Landfill

An initial landfill (Figure 18) is currently being constructed with the sand produced in the refinery and the press filtered residue will be deposited over this sand layer.

Figure 18 – Palmital Conquest Landfill

4. IMPURITIES

The replacement of the condensate and industrial water by Palmital water will increase the input of impurities in the refinery and the reduction of caustic losses by using press filter will reduce the impurities purge. Both effects can contribute to elevate the refinery impurities content.

However, a new bauxite source, called Barro Alto, with a high purity level, is being introduced in the bauxite blend feeding the plant.

A balance was done to predict the behavior of the impurities in the plant and determine the actions that should be taken to avoid production and quality problems.

4.1. Sodium Carbonate

As expected, sodium carbonate concentration will rise in the plant. A side stream causticization unit using washer overflow will be installed to guarantee the causticity of the pregnant liquor and the precipitation productivity. A direct causticization of Palmital water is also being studied.

4.2. Organic Carbon and Inorganic Impurities

Barro Alto bauxite presents a very low impurity content (Table 2).

Parameter	%
Available Alumina	> 50
Reactive Silica	< 2,5
Organic Carbon	< 0.06

Table 2 – Barro Alto Bauxite Quality

By introducing this bauxite into the plant, the input of organics will decrease significantly, compensating for the organics purge reduction caused by press filter.

In addition, the Oxalate Critical Concentration has been established and the plant will run below this point to maintain a safety margin.

Inorganic impurities are not expected to be significantly affected by using this new bauxite source.

5. BAUXITE RESIDUE AS RAW MATERIAL

Votorantim Cimentos (VC) is one of the largest cement producers worldwide with more than 100 plants. The company has a research center in Curitiba Brazil. Two cements plants are located within 30 km of the Votorantim Metais alumina refinery. The total production capacity of these plants is 6 million tons per year of OPC (Ordinary Portland Cement). Currently, no pozzolan is used in those plants. This presents a very good opportunity to convert bauxite residue into a pozzolanic raw material, reducing the cement cash cost.

5.1. Converting Bauxite Residue into Pozzolan

The process for producing artificial pozzolan (calcined clay) normally uses large amounts of calcined kaolin clays (Manfroi, 2009; Montini, 2009; Ribeiro, 2011; Liberato, 2012). Some bauxite residues may contain residual amounts of kaolin that when calcined can produce material with these same pozzolanic properties (Labrincha, 2010; Antunes, 2011; Fortes, 2013).

However, VM/CBA bauxite residue does not contain kaolin and has a relative high content of sodium, which prevents it of being transformed into a pozzolan simply by heating. To enable the residue to be used, its chemical composition needs to be adjusted and a high temperature is required to transform the mineralogy. This forms new compounds with pozzolanic properties and acceptable color.

The pozzolanic reaction is described by the equations in the Figure 19.

Calcium Silicate + Water → Hydrate Calcium Silicate + Calcium Hydroxide (a)

Calcium Hydroxide + Pozzolan → Hydrate Calcium Silicate (b)

Figure 19 – Pozzolanic reaction

5.2. CBA Bauxite Residue Characterization

VM/CBA bauxite residue characterization was obtained by X-ray diffraction (Figure 20) and X-ray fluorescence analysis (Tables 3 and 4).

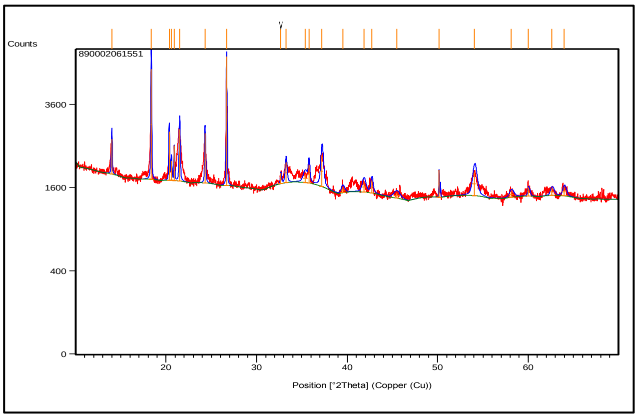

Figure 20 – Residue diffractogram

CBA Bauxite Residue DRX Analyse		
Parameter	Scale Factor	Chemical Formula
Quartz	3,3	SiO_2
Gibbsite	25,3	$Al(OH)_3$
Cristobalite	19,3	SiO_2
Hematite	23,3	Fe_2O_3
Sodalite	0,21	$Na_8(AlSiO_4)6(CO_3)2(H_2O)4$

Table 3 – Residue Mineral Composition

CBA Bauxite Residue FRX Analysis			
Parameter	%	Parameter	%
CaO	3,3	K_2O	0,42
Fe_2O_3	25,3	Na_2O	8,0
SiO_2	19,3	SO_3	0,53
Al_2O_3	23,3	TiO_2	3,4
MgO	0,21	Moisture	25,0
P_2O_5	0,61	LOI	15,8

Table 4 – Residue Chemical Composition

5.3. Pozzolan and Cement Production

In a pilot plant VM/CBA bauxite residue was blended with limestone and aluminous clay to adjust the chemical composition and the mixture was calcined at 1.150°C to produce the pozzolanic material. Figure 21 shows a photograph of the pilot kiln. The process flowchart is showed in Figure 22. This process can be run in a regular clinker line production.

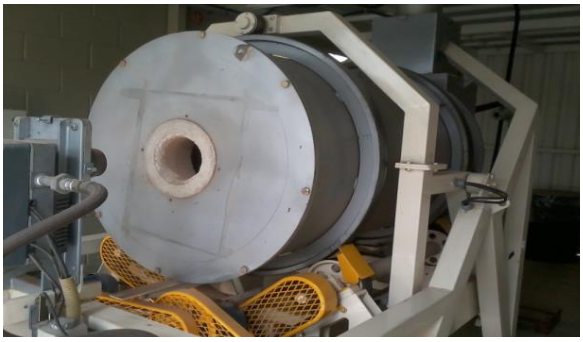

Figure 21 – Pilot Kiln

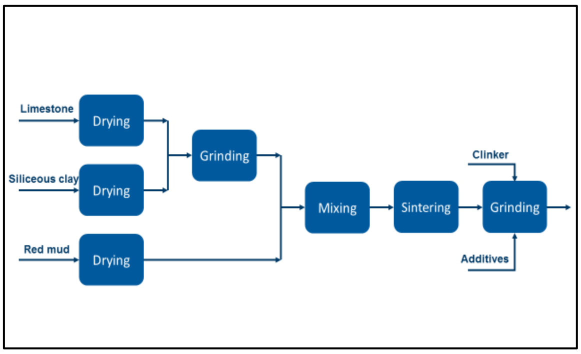

Figure 22 – Pozzolan Process Flowchart

Mixtures of standard cement and the produced pozzolanic material in the proportions of 15.0% and 30.0% of pozzolan was prepared to produce CPIV-32 ENV197 (CP IV/A) and CP II-Z-32 (CP II/A-Q) cements, respectively.

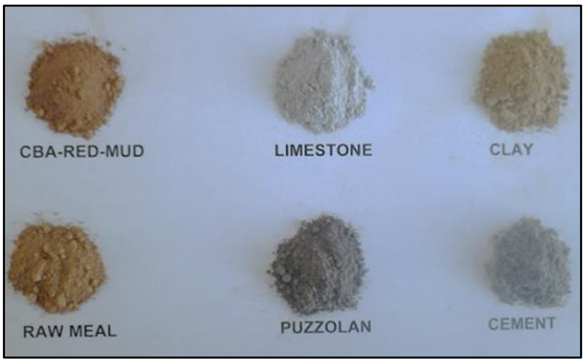

Figure 23 – Materials, pozzolan and cement

Figure 24 – Cement with Bauxite Residue and Regular Reference Cement

Figures 23 and 24 show the pozzolan raw material, pozzolan and produced cement.

5.4 Cement Quality

Strength tests were performed in standard cement (reference material), CPIV-32 ENV197 (CP IV/A) cement (30% pozzolan) and CP II-Z-32 (CP II/A-Q) cement (15% pozzolan). The results (Figure 25) met the specifications for the respective cements. The strength value meets a similar strength to the reference value after 60 days.

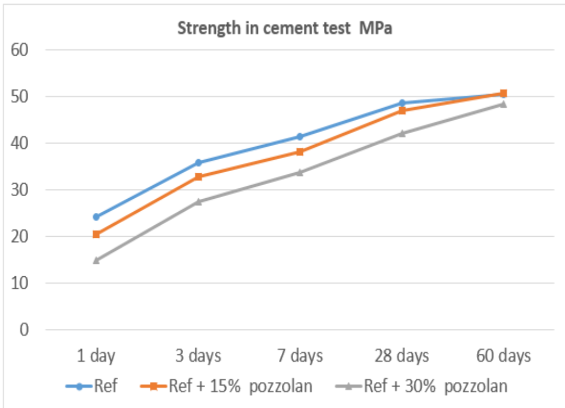

Figure 25 – Cement Strength Test

Strength testing was also performed on the concrete produced with the pozzolanic cements and the results met the respective specifications (Figure 26). As in the cement test, the strength value meets a similar strength to the reference value after 60 days.

The color of pozzolan is also important. Red colored pozzolan can not be used in the OPC production. The pozzolan produced with this technology is the same clinker color.

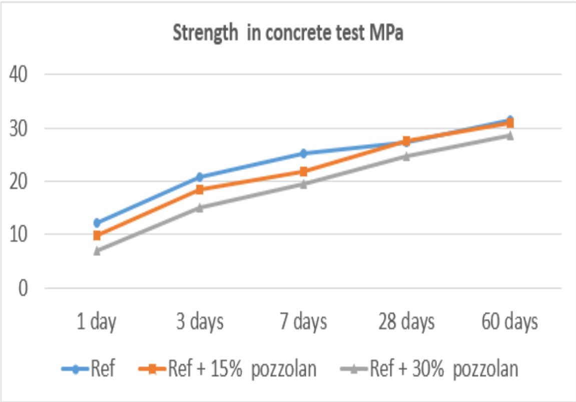

Figure 26 – Concrete Strength Test

Pozzolan produced with bauxite residue has the added advantages of lower energy consumption and lower CO_2 emission (carbonate content and fuel) when compared to clinker production.

A Brazilian green patent was requested for the developed technology (Patent number BR 10 2013 024226-8) as well as its international extension over 30 countries (PCT/BR2014/000208). Votorantim Metals and Votorantim Cement share the patent ownership.

Next step will be an industrial test in a Votorantim cement plant close to VM/CBA alumina refinery.

6. CONCLUSION

Using Dry Disposal Technology it is possible to increase the lifetime of the existing disposal area, reduce the residue soda content and store the residue in a more secure and environmentally sound manner.

Adjusting the chemical composition of the bauxite residue is possible to transform it, using a traditional clinker production line, to produce a good quality pozzolanic material. This can be used to replace up to 30% of the clinker in OPC while maintaining the quality of cement and concrete.

When compared to clinker production, the use of bauxite residue to produce pozzolanic material can reduce CO_2 emission as well as decrease fuel consumption. This is due to lower carbonate content in the bauxite residue..

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7. REFERENCES

Nery, K, Seno, R, Moreno, R, Scarmino, M and Pimenta, J. Study of Alternative Technologies for Residue Disposal (Red Mud). Light Metals. 2014; 161-163.

Manfroi, Eliz Paula. 2009. Avaliação da lama vermelha como material pozolânico em substituição ao cimento para produção de argamassas. Santa Catarina : Universidade Federal de Santa Catarina, 2009.

Montini, M, et al. 2009. Aplicações do resíduo de bauxita e da cinza pesada da indústria do alumínio na fabricação de cimento Portland. São Paulo : Congresso Brasileiro de Cerâmica, 2009.

Ribeiro, Daniel Véras. 2011. Influência da temperatura de calcinação nas propriedades cimentícias do resíduo de bauxita. São Carlos: Universidade Federal de São Carlos, 2011.

Liberato, Caio César, et al. 2012. Efeito da calcinação do resíduo de bauxita nas características reológicas e no estado endurecido de suspensões com cimento Portland. São Paulo : USP, 2012.

Labrincha, J. A., Morelli, M. R. e Ribeiro, D. V. 2010. Use of Red Mud as Addition for Portland Cement Mortars. 2010.

Antunes, M L P, Conceição, F T e Navarro, G R B. 2011. Caracterização da lama vermelha brasileira (resíduo do refino da bauxita) e avaliação de suas propriedades para futuras aplicações. Rio Claro : UNESP, 2011.

Fortes, Gustavo Mattos. 2013. Obtenção e caracterização de cimentos sulfobelíticos sintetizados a partir do resíduo de bauxita. São Carlos : Universidade Federal de São Carlos, 2013.