Decarbonization Applying Micro-fragmentation in Bauxite Mining from Hydro Paragominas, Brazil

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Abstract

Mineração Paragominas (MPSA), located in Paragominas city, state of Pará, is one of the main bauxite extraction operations in Brazil. The mine has a nominal capacity of 11 million tonnes of bauxite product per year, which are transported by pipeline to the refinery, located in the municipality of Barcarena, also in the state of Pará. The mine applies strip mining method for exposure, mechanical rock dismantling and loading of the ore, which is transported to the beneficiation plant. Conventionally, bauxite mining operations use the mechanical rock fragmentation method with surface miners, hydraulic excavators and dozers. However, since 2023, MPSA has been testing and implementing the rock dismantle with micro fragmentation. It was found this type of rock blasting is a technique that can significantly contribute to the reduction of diesel consumption in mining operations using controlled explosives. The process consists of a chemical reaction to release energy in the form of shock waves and gases, used in the biggest mines all over the world. The gases resultant of the blasting have a composition of CO_2 = 14.76 %; H_2O = 58.37 %; and N_2 = 26.87 %. It is possible to compare the amount of CO_2 generated by explosives and by conventional mechanical mining equipment. Although the use of micro-fragmentation itself does not eliminate CO_2 emissions, the efficiency of the blasting leads to a considerable reduction in mechanical energy consumption and, consequently, a lower need for equipment that consumes fossil fuels, such as surface miners, hydraulic excavators and dozers. Thus, it is estimated that the use of micro-fragmentation in MPSA in the next years will generate an annual reduction of approximately 5 thousand tonnes of CO_2 emitted (approximately 41 % less than the CO_2 emitted by mechanical mining).

Keywords: Bauxite, Decarbonization, Micro-fragmentation, Explosives, CO_2 emissions.

1. Introduction

Mineração Paragominas (MPSA), located in Paragominas city, state of Pará, Brazil, is one of the main bauxite extraction operations in Brazil. Production started in 2007, and the mine has a nominal capacity of 11 million tonnes of bauxite product per year. The bauxite with is processed and transported in the form of slurry by pipeline to the refinery, located in the municipality of Barcarena, also in the state of Pará.

According to geometric and spatial characteristics of the bauxite deposit (occurring on flat plateaus), with mineralized bodies presenting an average thickness of 2 meters in a tabular and horizontal form, with average capping of around 13 meters, the mining method used at MPSA is strip mining. The method basically consists of mining the deposit in successive strips, with the overburden removed from a given strip being thrown into the pit resulting from the mining of the immediately preceding strip. This results in minimizing the distance of transport of overburden, an important factor for the extractive activity in question, given the high waste/ore ratio, which is around 6.47 in volume. Bauxite mining at MPSA consists of the following stages:

a. Vegetation removal and cleaning of mining areas.
b. Removal and storage of organic soil.
c. Overburden removal.
d. Mechanical dismantling of the bauxite layer.
e. Excavation and loading of bauxite.
f. Spreading of organic soil and recovery of mined areas.

Figure 1 shows the geometry of mining area.

Figure 1. Mine geometry.

The entire mine operation process described is carried out using diesel-powered equipment. In 2024, the total diesel consumption for all processes, including overburden removal, mechanical dismantling, ore production and mine infrastructure, was 33.64 million liters, inducing CO_2 emissions of almost 90 000 tonnes. In this context, Hydro has global sustainability goals, such as a 30 % reduction in emissions by 2030 and zero emissions by 2050 and has been developing studies and initiatives to reduce its carbon footprint.

As highlight, since 2023, it is in an advanced stage of study the replacement of the conventional mechanical dismantling of the bauxite layer for a new method that's say micro fragmentation. Micro fragmentation is a project that uses drilling and controlled blasting with explosives, and the main objective is to reduce the burning of fossil fuels and, consequently, carbon emissions. MPSA is the first bauxite mine in Brazil to use this technology and has been obtaining positive gains with reduction in diesel oil consumption and estimated costs.

2. Conventional Mechanical Dismantling of the Bauxite Layer

Bauxite compressive strength ranges from 20 to 50 MPa, so according on its characteristics, it requires mechanical dismantling before loading for beneficiation.

The process of mechanical dismantling and fragmentation of bauxite is the object of this study, where historically the conventional mining method with equipment powered by diesel combustion, divided in four steps:

a. Surface miners: responsible for 65 % of the volume moved of ore annually, whose operating principle is the simultaneous fragmentation and loading of trucks. However, this equipment leaves a volume equivalent to 10 % of the area mined volume on the sides and manoeuvre areas (access).

b. Hydraulic excavators: carries out only mechanical dismantling of the sides and manoeuvre areas of the mined areas with surface miner. This material being loaded by wheel loader.
c. Large dozers: responsible for 25 % of the volume of ore moved, applied as a replacement for surface miners in need of scheduled maintenance and areas with smaller extensions as mining limits where it's not favourable to apply surface miner. This material being loaded by wheel loader.
d. Wheel loader: used for loading fragmented material by excavator and dozer.

For the MPSA's mechanical displacing activity and annual ROM (Run-of-Mine) production, equivalent to 16 million tonnes of bauxite, 17 230 hours of surface miners (112 litres of diesel per hour worked), 3 215 hours of hydraulic excavators (48 L/h), 5 583 hours of D11 dozers (121 L/h) and 4 861 hours of wheel loaders (50 L/h) are used. This equipment has high specific diesel consumption per hour worked, making this activity a challenge in terms of carbon footprint and operating costs.

Figure 2 shows the dismantling operation with surface miners and dozers.

Figure 2. Mechanical fragmentation. Left: Dozer D11, Right: surface miner.

Another important point to highlight is operator ergonomics during mechanical disassembly operations with tractors, due high vibration into equipment and high risk of injury. Therefore, this activity requires operator rotation every three hours, with the same operator remaining out of service for the remainder of the workday, increasing labor requirements and, consequently, operating costs.

3. New Technology: Application of Micro-fragmentation in MPSA

Aiming to meet global sustainability goals and reduce operating costs, brainstorming and specialized consulting were used to develop a new methodology for the bauxite fragmentation process. Based on the principle that rock blasting with explosives is a technology commonly applied in other mining operations with favourable results, the MPSA, in an internal committee, initially decided to adopt micro fragmentation as a process innovation on a trial basis.

The process is divided into two stages:

a. Drilling.
b. Controlled blasting using explosive emulsion.

3.1 Drilling

Mining drills are used to create precise and controlled holes during drilling and blasting with explosives. Unlike mechanical displacing, which directly fragments the material through significant stress on equipment such as dozers, the purpose of drills is to create a network of holes in the rock mass for the application of explosives and then perform the fragmentation through detonation. Their structure is similar to other mining equipment, with differences in the drilling implements and accessories which feature high technology and control.

In tests carried out at MPSA are used small drills with an operating weight of 23 tonnes. The application of pumped emulsion has also been favouring the adjustment of the drilling mesh and, consequently, reducing the number of holes. Below are the results obtained by comparing the main variables carried out in relation with basic test design with drilling and blasting using explosives.

Table 1. Results achieved with drilling tests.

Operational variables	KPI	Basic design	Tests performed	Results
Drilling penetration rate	m/h	60	137	+128%
Average hole height	m	2,2	1,8	-25%
Sub-drilling	m	0,2	-	-100%
Drilling grid	m²	9	11	+22%
Number of holes / area	Number	1.666	1.363	-18%

Figure 3 shows the drilling equipment and mine area after blasting.

Figure 3. Micro-fragmentation. Left: Sandvik–DP1400i drill, Right: detonated area.

3.2 Controlled Blasting Using Explosive Emulsion

Emulsion are substances, or mixtures of chemical substances, found in any physical state, which present as their characteristics when correctly initiated (heat, friction, impact, etc.), the violent and very rapid chemical transformation of the particles, transforming them into gases, allowing the release of enormous amounts of energy in a short amount of time. This energy is applied to produce the fragmentation of the rock mass in the direction of the free face or that one presenting less resistance [1].

Rock blasting with emulsion is carried out by means of the dispersion of gases that occurs inside the bench holes after the deflagration of chemical reaction. The energy released after the detonation creates new fractures, extension of existing fractures, displacement of the rock mass and movement of the centre of gravity of the detonated mass. Simultaneously with the improvement of mining methods, the chemicals used for rock blasting have been undergoing a complex technological evolution, seeking to achieve greater optimization of results focusing on greater safety in handling, greater resistance to water, better fragmentation of rocks, lower cost per unit of rock blasted [1].

The chemicals used in the tests carried out at MPSA were pumped and cartridge emulsion. Pumped emulsion presented better results, compared to the cartridge emulsion, and it was standardized due to the following advantages:

a. High resistance to water (good application in the Amazon winter where there is high rainfall).
b. High detonation energy.
c. Mechanized application.
d. Smaller drilling mesh.

Table 2 shows the chemical composition of the emulsion.

Table 2. Typical composition of an emulsion [1].

Ingredient	Mass percentage	Formula
Ammonium Nitrate	77.1	$N_2H_4O_3$
Water	16.0	H_2O
Diesel oil	4.9	-
Emulsifier: Sodium Oleate or Ezorbitol Monoleate	2.0	$C_{24}H_{44}O_6$
%	**100**	**-**

The method is 100 % safe, with activation carried out up to 500 meters away by remote control and complying with all regulatory safety criteria for the process and people. This methodology is already used in iron and copper mining around the world and is being adapted to bauxite in an innovative way. Figure 4 shows the main benefits of micro fragmentation:

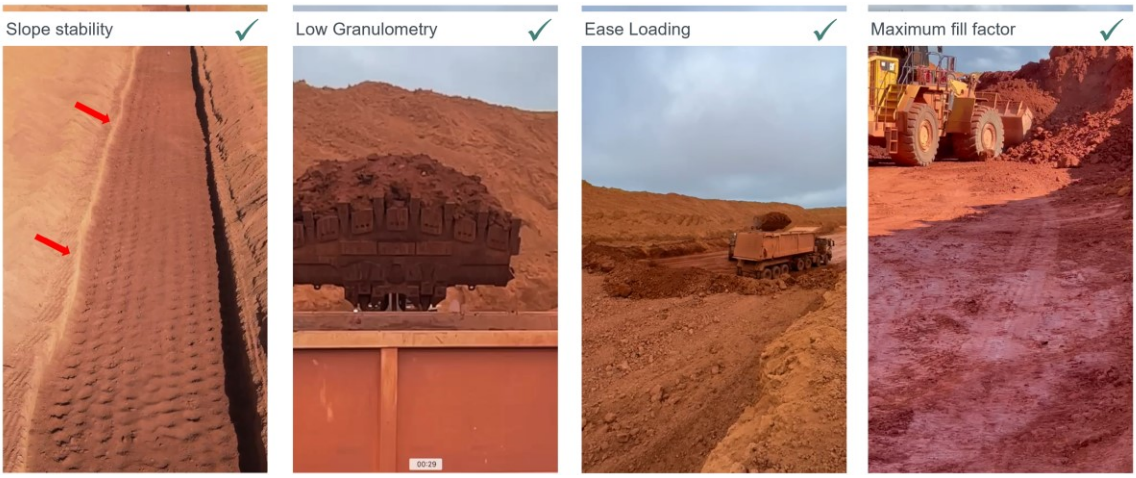

Figure 4. Main operation benefits of micro fragmentation.

4. Results

4.1 Environmental Gains

4.1.1 Gases Generated by the Conventional Mining Process

The use of conventional mining equipment generates gases that directly contribute to the greenhouse effect and are related to the burning of fossil fuels, the main one being carbon dioxide (CO_2).

MPSA's annual Run of Mine production is 16 million tonnes. For this movement, surface miners are used to carry out fragmentation in the conventional mining method, and trucks are loaded, corresponding to 70 % of production. The participation of surface miners is limited due to the manoeuvre area and strip sides where the equipment cannot access. Therefore, in addition, excavators and crawler tractors are added for fragmentation and wheel loaders for loading the remaining 30 % of the production.

Table 3 presents a summary of the specific consumption of diesel oil and the quantity of gases generated by the equipment in conventional method at MPSA, equivalents for a ROM production of 16 million tonnes.

Table 3. Summary of annual diesel consumption and gas emissions – conventional [2].

Equipment	Number	Total hours per year	Diesel specific consumption (L/h)	Annual diesel consumption (L)	t CO_2/L diesel	CO_2 Year (t)
Dozer D11	1	5 583	121	675 543	0.00267	1 803
Excavators	2	6 430	48	308 640	0.00267	823
Surface Miner	3	17 230	117	2 015 910	0.00267	5 380
Wheel Loader	1	4 862	50	243 100	0.00267	648
Total	-	-	-	**3 243 193**	-	**8 656**

4.1.2 Gases Generated by Micro-fragmentation Process

- Drilling

In the mining method using micro fragmentation, drills and explosives are used in the fragmentation process and a loader shovel for loading the trucks.

Table 4 presents a summary of the specific consumption of diesel oil with drills and the quantity of gases generated during drilling, equivalents for a ROM production of 16 million tonnes.

Table 4. Summary of annual diesel consumption and gas emissions–drills [2].

Equipment	Number	Hours Year	Diesel specific consumption (l/h)	Annual diesel consumption (l)	tCO_2/liter diesel[4]	CO_2 Year (t)
Drill	4	3 648	27	393 984	0.00267	1 051
Wheel Loader	3	5 491	50	823 594	0.00267	2 198
Total	-	-	-	**1 217 578**	-	**3 250**

- Application of Emulsion

According to the emulsion specification, each kilogram of emulsion generates, on average, 1 000 liters of gases. The annual plan for the use of explosives in the MPSA is 1 998 600 kg. Using this information, the volume and mass of CO_2 generated annually by the emulsion were calculated, as shown in Table 5 (for a temperature of 27 ºC and a pressure of 1 atm).

Table 5. Annual quantity of gases generated by emulsion [3].

Data	CO_2
Annual mass of emulsion (kg)	1 998 600
t CO_2/ t emulsion	0.1661
Total mass of CO_2 annual (t)	**332**

4.1.3 Comparing the Two Methods

Table 6 presents a comparative summary of the main greenhouse gases generated by equipment applied with the conventional method in relation to the micro-fragmentation process.

Table 6. Comparison of gases generated in the two mining processes.

Process	CO_2 (t)
A. Conventional mining	8 656
B. Micro-fragmentation	3 582
Difference (A-B)	5 074
Reduction with micro-fragmentation	**41.4 %**

4.2 Costs

In addition to environmental gains, the application of micro fragmentation with small drilling machines projects financial gains through reduced diesel consumption and investments in the acquisition of large equipment. Figure 5 projects financial gains of 14 % in Opex and CapEx over an 8-year period, comparing the two methods.

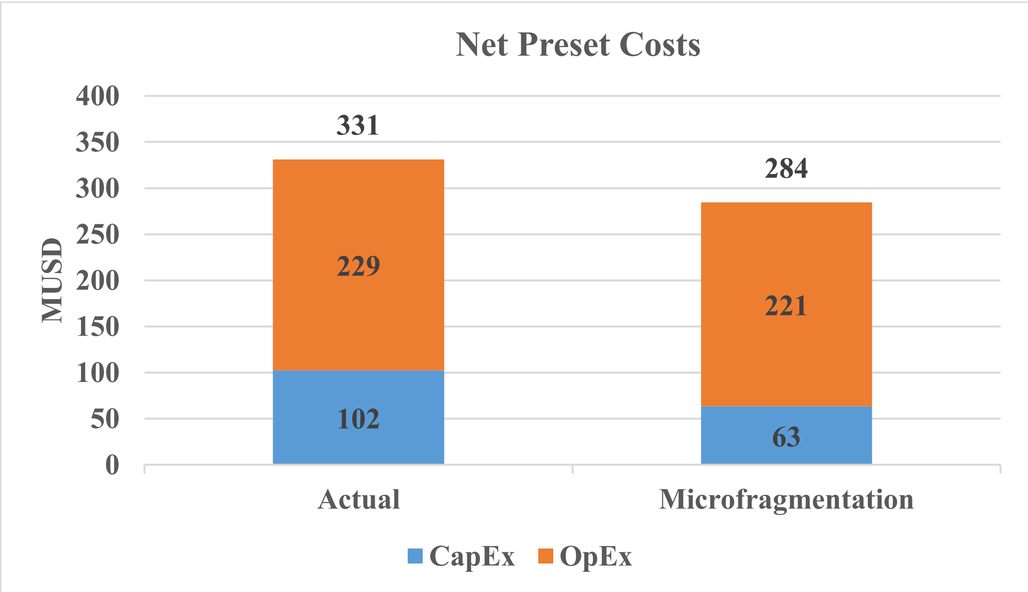

Figure 5. Financial gains.

5. Conclusions

Application of the micro-fragmentation process in MPSA mining operations has shown excellent results in terms of performance, when compared to initial estimates, related to use of drills in drilling activities as improved productivity in penetration rate (m/h: more 128 %), drilling grid (m^2: 22 % reduction) and number of holes per area (600 × 25 m: 18 % reduction). Which provided positive economic forecasts with net present cost of micro-fragmentation is 14 % lower than the conventional method.

The most relevant advantage of this new method in relation to the conventional method (surface miner, hydraulic excavator and tractor) is the significant reduction in greenhouse gas emissions. Among the main benefits is the reduction of CO_2 in the order of 5 075 t per year (41 %), as shown in Table 6.

MPSA is in the final testing phase and beginning the partial transition process to micro-fragmentation. For the coming years, a 70 % share in the rock dismantling process using new methodology in MPSA bauxite mining is already expected.

6. References

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