特集記事 • 1
鉄の環境との共生

Eco-friendly Mining Technology with Fully Integrated Sustainability from Mine to End-users : CBMM, Brazil

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Abstract

Companhia Brasileira de Metalurgia e Mineração – CBMM – is fully integrated from its mine to final niobium products such as ferroniobium used in the steel industry, special niobium oxides, vacuum grade niobium masteralloys and niobium metal. CBMM's sustainable program transformed niobium from the laboratory dream of the early 60's into the technology solution for today's challenges represented by the continuously increased need for infrastructure, high energy prices and growing environmental concern. The company has created and maintained its long-term program for niobium development with anticipation of environmental regulation, investment in human resources, building strong and sustainable relationship with its community, developing technology to exploit its mineral resources with continuously increased efficiency and creating value-added solutions in every supply chain involving the end-uses of niobium, such as gas pipelines, automotive industry, structural applications, shipbuilding and aerospace. This paper presents examples of main actions taken over the past 45 years to build CBMM's sustainable niobium program from its mine in Araxá, Brazil to every niobium end-user in the world.

要旨

世界のニオブ (Nb) 需要の90%以上がブラジルより供給されており、CBMM社はその実に90%以上を生産している。日本のNb需要の約97%は鉄鋼分野であり、ステンレス鋼、石油ラインパイプ、自動車用薄鋼板などの主要合金元素として近年増加傾向にある。

Nbはブラジルで産出されるパイロクロア鉱石 (2.65% Nb_2O_5) を粉砕―磁気選鉱―浮遊選鉱―浸出処理工程を経てパイロクロア精鉱 (65% Nb_2O_5) とし、鉄鋼原料用は直接テルミット還元法によってフェロニオブに加工される。高品位の金属Nbに関しては、同精鉱を溶媒抽出によって高純度酸化ニオブとした後テルミット還元される。

CBMM社は、Nbの採鉱からエンドユーザーに供給される様々な最終製品までの全てを一貫製造・管理する会社であり、その持続可能な企業経営プログラムは、1960年代初頭には単なる実験室の夢の金属であったNbを、今日拡大の一途をたどる社会基盤整備、エネルギー問題、環境問題解決への様々なチャレンジに応える切り札の金属元素へと変貌させた。

CBMM社が築き上げたNb開発の長期プログラムは、環境規制への配慮、人材への投資、地域社会との強固かつ恒久的な関係構築、ガスパイプライン、自動車産業、鋼構造物、船舶、航空宇宙分野などの全てのサプライチェーンにおける高効率・高付加価値化を念頭に置いたNbの有効活用に対する技術開発からなる。

本論文は、環境特集号出版に当り、資源大国であるブラジルにおいて環境との共生を社是として過去45年築き上げたCBMM社の持続可能な企業経営プログラムの内容を紹介頂き、鉄の環境との共生を考える一助としたい。なお、CBMM社は日本鉄鋼協会論文賞 "ギマラエス賞" の提供企業です。

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1 Introduction

The unprecedented grow of the steel industry in the last 5 years demanded a fast reaction from the entire supply chain involved. In Brazil, it is observed that this strong consumption of raw materials and energy has been followed closely by an increasing concern with environment and sustainability, in order not to lose all the efforts made in this direction in the past and to guarantee future supply.

The upturn in demand was specially noticed in micro-alloyed steels, once their application has been increasing exponentially in modern and higher performance projects. Niobium is used mainly as a micro-alloying element and the growth in its consumption has been higher than the increase in crude steel production in the world, Fig.1.

This paper presents an example of an eco-friendly Brazilian mining company that, for the past 45 years, has built a program which allowed it to overcome all these challenges, being always in agreement with the sustainability concept. It presents some practical examples of this policy as applied to mining management and supply chain, used as well by its customers and end-users.

CBMM is the world leader in niobium ore deposits, controlled and managed by Moreira Salles Group since 1965. The company is fully integrated from mine to final products, with 40 years of investment in niobium technology and applications, creating new markets and proprietary industrial processes.

The open pit mine, Fig.2, is located at a carbonatite complex, a circular area with surface diameter of five kilometers. The mine is predominantly a formation of dolomite carbonatite with calcite carbonatite and the primary ore. The weathered material, derived from this primary ore, is now being mined and contains about 4% of bariopyrochlore, the main niobium mineral[1].

Proven reserves are estimated at 200 years with about 75.000 t of FeNb/year, based on 2008 production. Of the total, 95% of production is exported.

Sustainability in mining practices can only be achieved by addressing the fundamental aspects of social, environmental and economical impacts, without generating any debts for the future[2]. CBMM anticipates regulatory legislation since the beginning and its policy is to be always stricter than regulations.

CBMM's "Niobium Program" is conducted under a sustainable scenario. Its mineral resources are unrivaled in size and quality and the company knows them in great detail, which ensures great flexibility and efficiency in its usage.

Efficiency in using niobium means not only its production process optimization, but also the strategy for its application, the approach of the program is used from the mine to the end-users : CBMM promotes niobium for the applications to improve products performance and also to increase value for the final product.

2 Eco-Friendly Mining Technology in CBMM

2.1 Implementation of ISO 14.001 Environmental Management System

Environmental awareness and sustainability issues were already present since the start of mining operations in the 60's. When the standard was published in 1996, CBMM understood that the ISO 14.001 system would help to formalize the on-going of its sustainability program. As a result, CBMM was the first company in the world to be certified by ISO 14.001 in mid 1997. The main reason for such fast and successful implementation was due to the fact CBMM was already operating according to the best environmental practices and had the understanding, align-

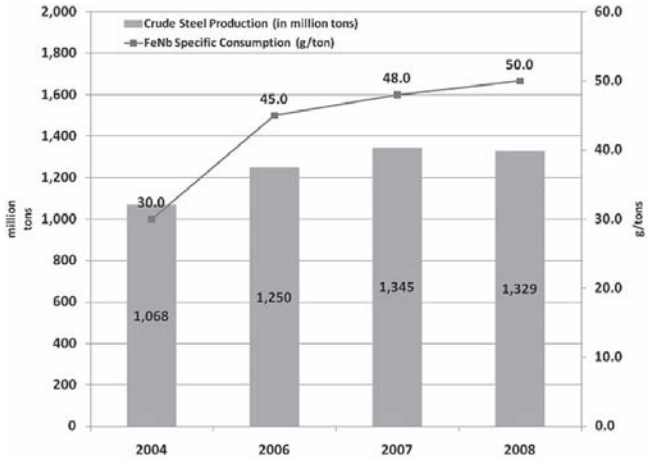


Fig.1 Crude steel production and specific ferroniobium consumption in the past five years in the world

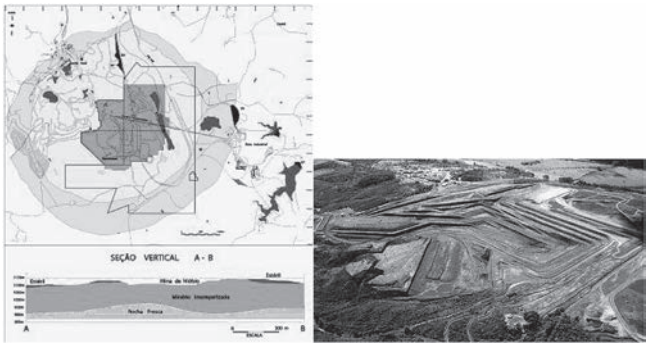


Fig.2 Open pit mine of CBMM with a scheme showing the weathered material over the fresh rock[1]

ment and co-operation of employees and community on process efficiency and environmental awareness. From that point on, continuous improvement has led to CBMM gaining widespread recognition not only from local authorities and agencies but also from its customers worldwide.

2.2 Process Control and Environment

Full attention is given for getting the best process efficiency, being innovation and process control key points. All air emissions, stacks and water disposal are continuously monitored to ensure full compliance with environmental standards. Modern equipments, under the coordination of CBMM central laboratory - certified by ISO 17.025, enable CBMM to successfully comply with 886 environmental items.

As an example, the monthly average of air quality from January to May 2009 was 34 μg/Nm^3, almost five times bellow the standard limit of 150 μg/Nm^3. The lowest figure obtained in the plant compares favorably to the average of 38 μg/Nm^3 in the urban area, during the same period.

Dust collectors capture the finely emitted material, the majority of it is recycled. The remaining minority is sent to proper deposits. From May 2008 to May 2009, the particulate reading at CBMM's facility was 18.5 mg/Nm^3, eight times less than the standard limit of 150 mg/Nm^3.

Currently, water recycling is 88% and the target is to achieve 95% by 2012. . After a natural clarification process, water is treated and pumped back to the industrial complex. The tailings are transferred to dams. High density polyethylene coats are applied to the entire extension of the new tailing dams. Monitoring wells are located all over the surroundings for control of specified elements. The quality of the discharged effluent is monitored daily with results consistently below standards, Table1.

Fig.3 shows the process production flow, highlighting the main products and by- products generated. CBMM is constantly studying ways to make use of all by-products resulting from niobium extraction and concentration process. An example is the magnetite present in the ore, around 25% in volume; nowadays it is being separated and made available for steelmakers. CBMM estimates to send to steelmakers around one million tons of this material per year.

Another development regards the re-utilization of Al_2O_3 in the slag formed during aluminothermic reaction for the production of FeNb. Up to 75% of the aluminum that is used to reduce the niobium oxide to FeNb is recovered as Al_2O_3 and will be sent to the market, reducing approximately 46% of alumina slag volumes and transforming waste into valuable raw material.

The company also promotes environmental awareness through various activities of its Environmental Development Center. The center consists of :

・Plant nursery : research is undertaken to protect and harvest trees threatened by extinction. The trees are then returned to their natural setting.

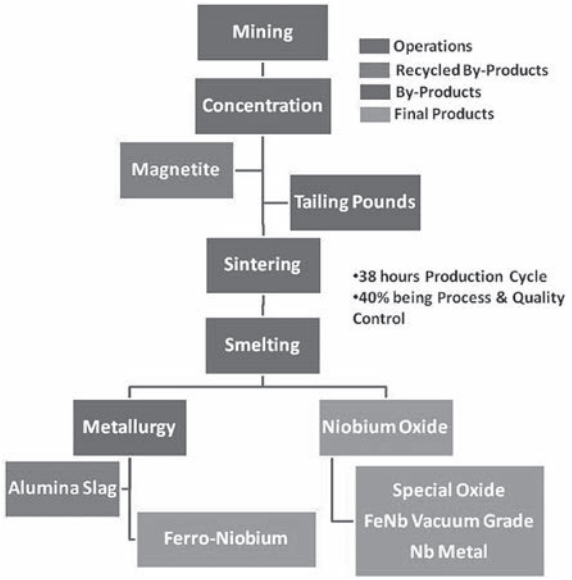


Fig.3 CBMM process flow, main products and by-products

Table 1 Water effluent discharged control with standard limits and the average of 12 months (May 2008 to May 2009) of different parameters

Element	Standard limits	Monthly average values
Barium	0,7 ppm	0,49 ppm
Chloride	250 ppm	86 ppm
Fluorine	1,4 ppm	0,37 ppm
pH	6,0 to 9,0	7,1

More than one million trees comprising 150 different species have been re-introduced in CBMM property and in protected areas like spring waters and river beds. The Center is capable of developing 50,000 seedlings per year.

- Animal nursery : research and assisted reproduction of native local species are promoted. CBMM conducted the first successful assisted reproduction of the Brazilian Lobo Guará, a small regional wolf that nearly had become extinct.
- Education center : since 1992 CBMM has hosted students and teachers, approximately 3,000 each year.

2.3 Health, Safety and Community

CBMM's view on human resources has created a culture that understands the need for quality, health, safety and productivity. The health and well being of its employees and partners are the base for a sustainable business : health and safety programs have the target of an accident free workplace. No occupation related illnesses has been reported during the past six years. In addition, absenteeism is bellow 0,5% and turnover is less than 1%, 2008 figures. The results of such numbers are a proper training of the work force and a high productivity. The company believes that all these characteristics are intimately linked and they all lead to the quality and productivity needed to be a global leader.

Mining operations have a conservative approach, using 22° slope angles instead of the allowed values of 33°, just to have full guarantee of no injuries. The number of trucks inside the facility is limited as much as possible with the use of the 3.2 km conveyor belt every time it is applicable. The conveyor operates from the mine to the mill since 1981. In 1994, the niobium oxide reduction with aluminum started to be controlled inside electric arc furnaces, instead of having an open-air operation. In 2000, the concentrate refining by HCl leaching process was replaced by pyrometallurgy. These are good examples of CBMM awareness to health, safety and environment.

Management system is based on the total participation of the employee, informing and acting to correct and prevent incidents. Motivation towards the accident free is remarkable : all investments, new processes and daily simple decisions must consider this. All CBMM internal procedures for safety follow the standard requirements of OSHAS 18.001/2007 as certified by ABS-QE since 2002.

CBMM invests in future generations : a pre-school for the employees' children is financed from the day they are born until they have reached the age for official schooling. The company also has substantial tuition coverage for children's complete educational cycle, including college education. This support is not limited to the employees. The company also has invested in a vocational school for the city of Araxá that prepares 100 graduates per year. This is where CBMM recruits significant part of its skilled labor.

A long-term commitment has been established with this community and, for the last 40 years, around USD 80 million have been invested in social projects with special attention to : schools, day care centers, hospitals and restoration of public assets.

30 years ago, in a partnership with the local Union, CBMM started the Housing Program, developing its employees understanding about well being in living. In parallel, CBMM started to build and to finance houses for its employees. The program is in its third stage since its implementation, has already helped with the construction of more than 500 houses. 100% of housing needs are taken care of.

3 Niobium helping today's Innovative Challenges of Steel

The companies' goals are not only in supplying the niobium demand – in the form of ferro-alloy, oxide or metal – but also in providing and developing the technological potential involved in the use of this element, in discovering how niobium can help to overcome the main challenge faced worldwide : growing wisely and in a sustainable way, always conscious of energy savings, cost reduction and protecting the environment, Fig.4.

CBMM boasts a strong technical group constantly developing niobium applications, acting together with steelmakers, research universities, institutes and end users. At the moment, the company is involved with more than 40 research projects around the world.

At least 2% of the sales are invested in R&D. As a part of this technological effort, there are 237 re-

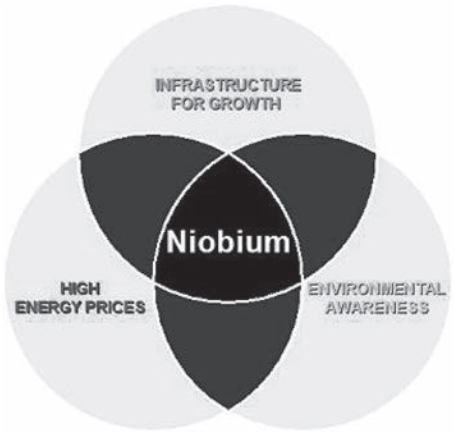


Fig.4 Today's challenges in which CBMM is concentrating the efforts with niobium as the proper solution

searchers in the steel industry that got their degrees with scholarships sponsored by CBMM in areas of relevance for niobium. This talent is installed worldwide and is receptive to niobium technology, helping to promote the "Niobium Program".

Traditionally, niobium is applied as a micro alloying element to obtain higher strength steels (HSLA), mainly used in automobiles parts, high-pressure gas transmission pipelines and structures. Niobium is also used in stainless steel for automobile exhaust systems, nickel-based super-alloys for turbines in aircrafts and also in heat resistant steels for energy generation. Other special applications include as well superconducting alloys for MRI magnets, electronic ceramics and camera lenses.

Some examples of these efforts are given in the following items.

3.1 Niobium in Steel for Automotive Segment

Major concerns in automobile production are the emission of greenhouse gases, mainly CO_2, and safety. The efforts have been focused on weight savings and stricter safety requirements, leading to the development of new steels and alloys, every percent of weight saved is associated with a 0.8% emission reduction[3]. The goal has been to optimize vehicle performance with little or no additional cost to the manufacturer and consumer. The increase of fuel consumption with the car average weight is shown in Fig.5[4].

Niobium is making possible the development of tougher steels and lighter components, allowing project improvements without compromising weight savings.

According to the World Steel Association[5], replacements of conventional steels for the car body, can result in a 17-25% savings. When that is applied to a typical five-passenger family car, the overall weight of the vehicle could be reduced by 117kg. This figure corresponds to savings of 2.2 tons of CO_2 in the operating life of the vehicle. The use of Niobium started in the HSLA steels, for higher strength materials used in the car body assembly. Afterwards, its benefits were also discovered for other steel families as it helps – through grain refinement – to improve: strength, elongation and toughness, Fig.6.

3.2 Niobium in Steels for Exhaust Systems

The continuous search for less pollutant emissions also proved to be the main driver in this case. Acting together with the demand for materials with longer lifecycles, sophisticated exhaust systems were developed using stainless steel.

Besides the improvements made in engine efficiency and in fuel quality control, the installation of catalysts in vehicles exhaust systems was necessary to accelerate the transformation of the toxic components (hydro carbons, CO and NOx), to non-toxic substances (H_2O, N_2 and CO_2).

The efficiency of those reactions is directly related to the temperature; the higher the temperature of the emitted pollutants, the more efficient the conversion. To obtain improved yield in fuel combustion and in catalyst conversion reactions, it was necessary higher temperatures in the reaction chamber of the engine and in its outlet gases, implying in higher working temperatures for the entire exhaust system. The temperatures started to reach maximum values of 900-950℃.

The solution for these components was the use of Nb-bearing ferritic stainless steels that simultaneously offer an effective compromise between mechanical

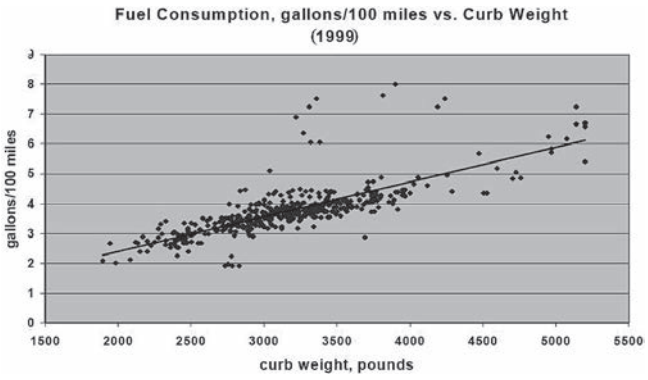
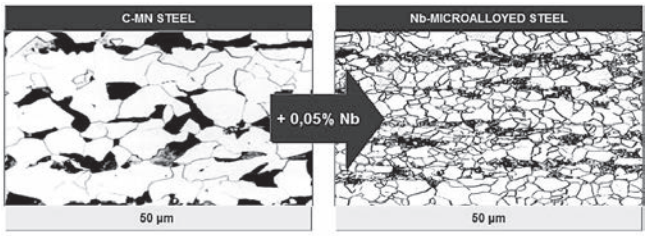


Fig.5 Fuel consumption (gallons/100miles) as a function of the curb weight (pounds) for new passenger's car vehicles fleet in the US, in the year 1999[3]



	STRENGTH	TOUGHNESS	FORMABILITY	WELDABILITY
Carbon content	+ +	- -	- -	- -
Solid solution hardening	+	- (+)	-	- (+)
Precipitation hardening	+	-	-	-
Dislocation hardening	+	-	- -	Neutral
Grain refinement	+ +	+ +	Neutral	+
Inclusions (Sulphur)	Neutral	-	- -	-

Fig.6 Effects of different strengthening mechanisms on the mechanical properties of steel

properties at high-temperatures, corrosion resistance and economical production costs.

3.3 Niobium in Steels for Energy : Generation and Transportation

Securing available energy at reasonable prices greatly influences life quality and economic growth. However, the power generation industry is facing stricter emission regulations due to governments' attempts to create healthful conditions for future generations[6]. World matrix is based on power generation by thermo electrical plants, where the heat resource most commonly used is burning of fossil fuels. In 2007, energy production accounted for 59% of all CO_2 emissions in the European Union countries. Worldwide, coal-fired plants generate approximately 8 billion tons of CO_2 every year[7].

Increase of power generation efficiency for generating more energy with less fuel is a global challenge. Efficiency can be influenced by a variety of parameters but high temperature and high pressure of water vapor (used in turbine operation) remain the major barriers to material performance. As a reference, 1% of thermal efficiency improvement on an 800MW generation turbine would reduce one million tons of CO_2 lifetime emissions[8], covering about 20 years.

A family of stainless steels - most of them containing niobium - is being developed to generate significant benefits in high temperature resistance, especially concerning creep and oxidation resistance.

Niobium is also helping to make energy available from its source to urban and industrial centers. Among the examples are the oil and gas pipelines. Niobium steels have high resistance and are tougher, resulting in pipes that can handle higher pressures. With these steels, the exploitation of remote gas and oil fields has become economically viable. Recently the West – East second pipeline in China started to be assembled, Fig.7 , a project with 7.700km of pipelines, for the transportation and distribution of the oil and gas across China.

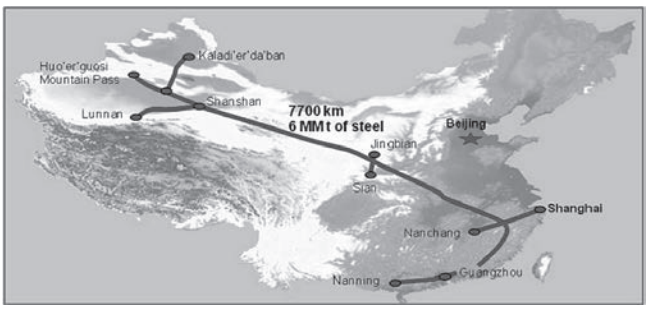


Fig.7 West-East Chinese second line with 7.700Km, 6,6million tons of steel

3.4 Niobium as Superconductor

One of the main challenges of the humanity are energy sources, generation and transmission. Superconductors promise to revolutionize power distribution by providing lossless transmission of electrical power. The development of superconductors with transition temperatures higher than the boiling point of liquid nitrogen make commercially feasible the concept of superconducting power lines, at least for high-load applications[9]. Experimental transformers using superconducting windings have efficiencies close to 100%, when applied to large heavily-loaded transformers, achieving significant annual savings in energy.

Of the many existing superconductors materials, only niobium based have been developed so far in to mature products. Superconductors containing niobium, specifically NbTi and Nb_3Sn, have become indispensable for producing the high magnetic fields required for different industrial and scientific applications. The most prominent application is Magnetic Resonance Imaging (MRI) for medical diagnostics, as it requires very strong, homogenous and stable magnetic field[10].

MRI is considered a powerful tool for use in medicine, biology and pharmacology because it generates tomography images of the human body, animals and food. Other than x-ray based computer tomography, it is virtually non-invasive as only magnetic fields and radio frequency fields are involved. It also provides a distinctly greater contrast of the different soft tissues of the body than computed tomography images. Consequently, MRI is especially valuable in neurological, musculoskeletal and cardiovascular imaging.

4 Conclusion

CBMM believes that mining business can be successful only if rooted in the sustainability concept. All activities, from the mine to end-users, have been developed according to this concept. The strategy is not to be merely a raw material supplier but to introduce niobium in applications to improve product performance and bring value to the production chain, always with energy savings, reduction of costs and environment protection in mind.

The impact of this philosophy is evident in CBMM's own standards, which are stricter than regulations. The company has anticipated environmental regulatory legislation since the beginning as it also believes that this is a cheaper and more efficient business proposition. This philosophy is evident in the automotive sector, where niobium has led to lighter vehicles with reductions in fuel consumption and CO_2 emissions. Niobium increased the life of ve-

hicles exhaust systems and reduced maintenance costs and CO_2 emissions. Niobium increased creep and oxidation resistance of stainless steel for boilers, allowing higher operation temperatures of the thermoelectric plants, increasing efficiency and reducing operation and maintenance costs. All CBMM investments, new processes and daily decision-making are influenced by environment, employees, community and product value.

These conditions are sustainable because CBMM is always attentive to make sure niobium products are value – driven.

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