Use of Nickel in Iron Slag for Paving Asphalt Concrete

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ABSTRACT: This study presents physical and chemical properties of iron nickel slag obtained from metallurgical Plants of Barro Alto and Niquelândia, owned by Anglo American and located in Goiás State, Brazil. Current results for real and apparent density, bulk density, particle size distribution by sieving, absorption and results for ligand physical characterization used in the mix are presented. Aspects related to the process for obtaining this material as a by-product in the FeNi Plant are also described. From slag samples analysis was possible to obtain a trace of asphaltic concrete mix, using the Pen50/70 and concentration of ligands equal to 5%, 6% and 7% in the the mixture, which was measured by Marshal method. Results of tensile strength tests, by diametrical compression, volume percentage of voids, empty bitumen ratio, stability and fluency, to determine the optimum binder content of asphalt mix are described. The results indicate that the iron nickel slag particle size distribution can be classified from medium to coarse sand, and, according to their chemical composition, can be considered as an inert material according to Brazilian norms for classification of waste ABNT - NBR 10004/2004. The high values of tensile strength, resilient moduli and stability, be a cluster point of promising use alternative paving in low cost.

KEY WORDS: slag, iron nickel, asphalt concrete.

1 INTRODUCTION

In recent years, the activity of recuperation of by-products has become essential regarding the necessity of environmental protection. The steel and metallurgy industries, in special, produce a big quantity of residues, according to the processes of iron, steel and other alloy production. Establishing alternatives to the employment of these residues is one of the great challenges from modern society, however, on the other hand, it is observed that many of these materials can be used as aggregates in works of asphaltic paving and civil construction, since it is guaranteed that that there will not be a transference of the environmental problem to the industrial area of infrastructure. Obviously, the new materials employed present physical and mechanical characteristics similar to the conventional aggregates. The approximation between the university and industry attains fundamental importance to the viability of new technologies.

The objective of the present study was to examine the feasibility of the use the iron nickel slag in asphalt concrete. The slag came from the process of reduction of two Metallurgical Plants of a mining company located in the state of Goiás. It is concerned to a compost aggregate of several chemical elements, constituting in a common residue in the fabrication of nickel contained in the iron nickel.

Both operations are responsible for the almost totality of the iron nickel production in the country, about 97,9% of the national production and the company is configured as one of the greatest worldwide producer of the metal. A considerable quantity of the ore (Figure 1) is employed yearly in this pyro metallurgic process, which comprehends the stages of Ore Preparation (Crushing, Homogenization and Drying), Calcination, Reduction e Refining. In the Reduction it is obtained the iron nickel, which, afterwards, is sent to Refining in order to remove its impurities, such as sulfur and phosphor. After this stage, the alloy is adequate to marketing. The iron nickel is used, mainly, in stainless steel industry. Either in Reduction, as in Refining, slags of the process are generated (Figure 2), being the slag from the process of reduction the object of this study.

Figure 1. Ore employed in the production of Iron nickel.

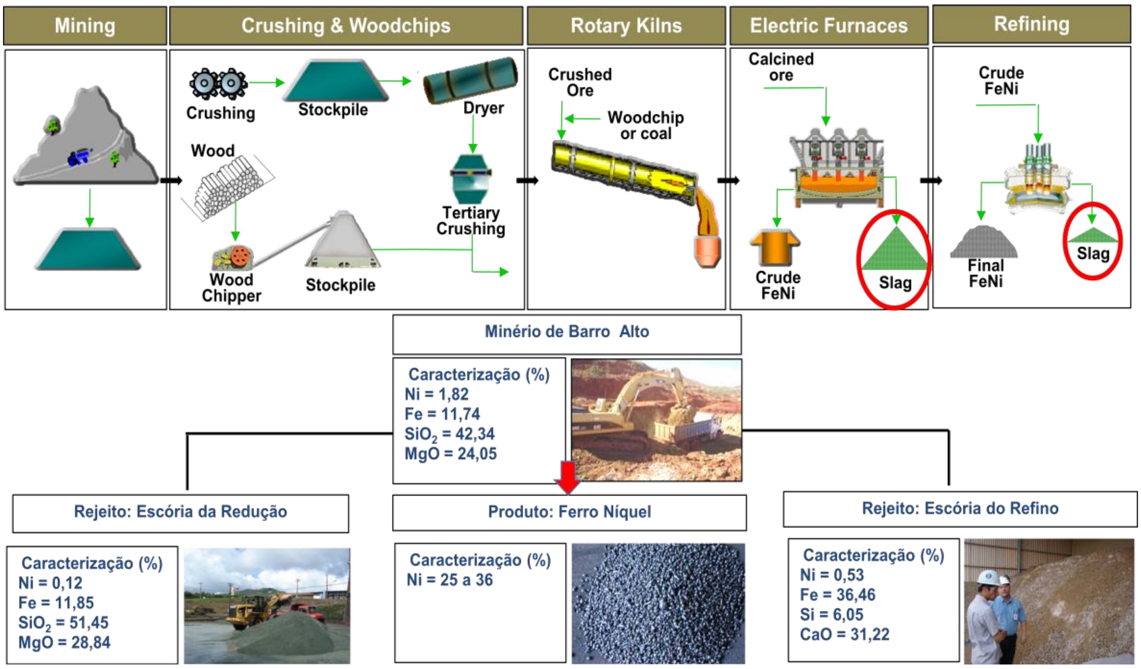

Figure 2. Process of iron nickel production employed in the Pyro metallurgic Plant from Niquelândia.

2 OBJECTIVE

To analyse the mechanical behavior of the asphaltic mix of asphalt concrete, containing the iron nickel slag as an alternative aggregate in road paving and as a material of possible application in low price works of paving. To contribute with the reduction of the deposits formed by residues and of the environmental risks in metallurgic industries.

3 MATERIAL STUDIED

To this study it was used the Reduction iron nickel slag from the two industrial Plants which belong to the Anglo-American Company in Goiás.

It must be highlighted that the iron nickel slags might present peculiar characteristics which can vary according to the ore fed in the metallurgic processes. Figure 3 presents a ternary diagram with the characteristics of the iron nickel slags in many Plants of the World.

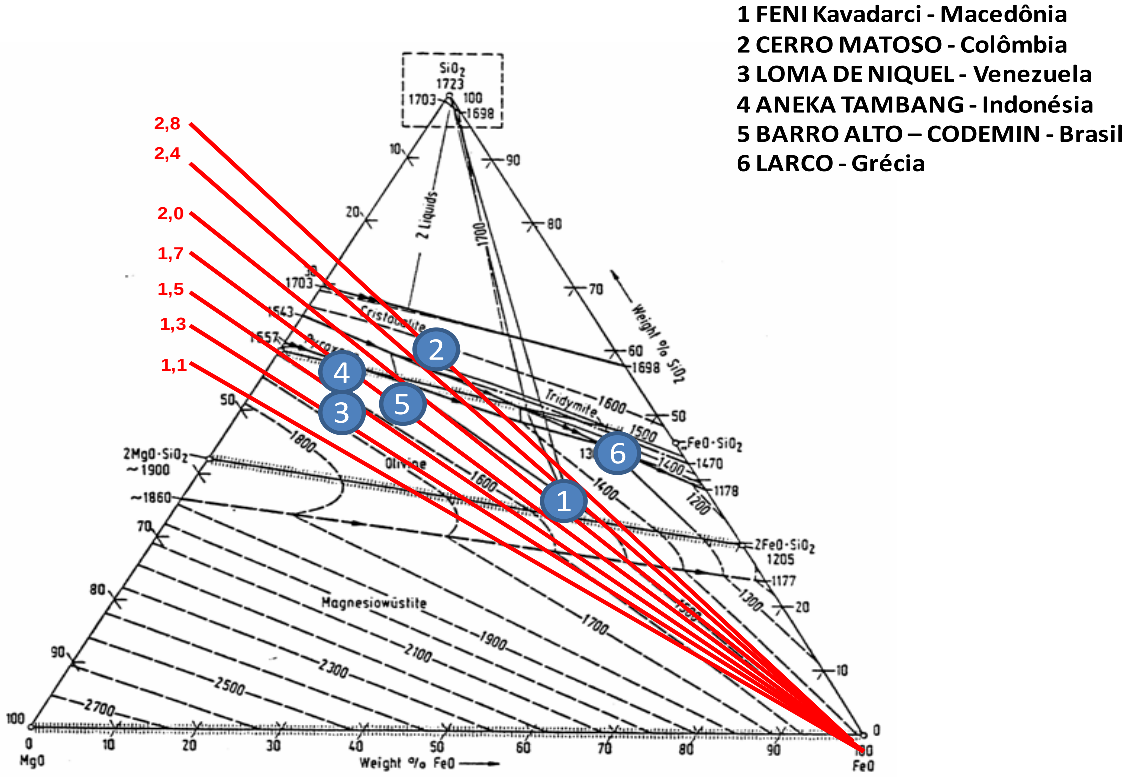

Figure 3 – Different kinds of iron nickel slags from some Plants of the World.

The industrial Plants from Barro Alto and Niquelândia operate with the same ore, which comes from Barro Alto Mine. For such reason, the slags obtained in its several processes are very similar. Niquelândia Plant operates over 30 years, and has a considerable deposit of slags in specific areas of deposition. The yearly slag generation in this Plant is approximately 430.000 tons, as for Barro Alto Plant, which started its operation in 2011, it will achieve a production of 1.850.000 tons of slag in 2015. As it was already mentioned, these materials are deposited in specific areas, and, as it is about considerable volumes to both operations, the costs with internal transportation, adequacy of the land to where it will be leaded, among other action, are considerably high.

The reduction slag contains high contents of silica (51% of SiO_2) and magnesium (28% of MgO) and it can be considered a material member from the olivine group, which are constituted by iron and silicate magnesium. The olivine usually presents itself with an olive green color, therefore its name. Figure 4 illustrates the iron nickel slag sample with its green tone, characterized by its chemical composition. Figures 5 and 6 show the slag stocks from Barro Alto and Niquelândia Plants, respectively.

Figure 4. Iron nickel slag sample.

Figure 5 – Slag stocks formed during the first years of operation of Barro Alto.

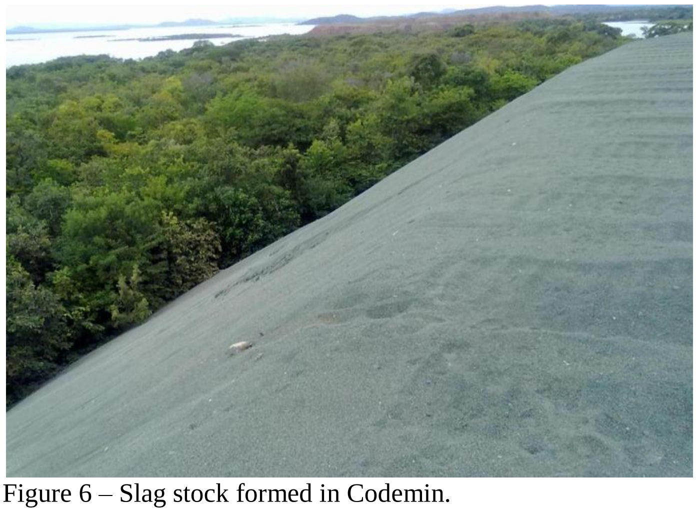

Figure 6 – Slag stock formed in Codemin.

The slag from reduction is generated in the process of fusion of the nickel ore in three-phase electric furnace, where the non-metallic elements such as: SiO_2, MgO and Fe are granulated in the presence of water.

4 CHEMICAL CHARACTERISTICS OF SLAG REDUCTION IRON NICKEL

A complete characterization of an aggregate is essential, particularly when it is an alternative material for certain applications. Its chemical composition will be one of the indications to determine the behavior and reactions of this material in contact with another household and external aggressive agents present in the environment. In some cases, chemical reactions occur that lead to faster degradation, or of a concrete pavement or any other structure of civil works.

The following shows the chemical composition of the slag and chemical characterization by solubilization and donated by the company producing the material.

4.1 Chemical Composition

The iron nickel slag is basically composed of the elements shown in Table 1 below:

Frame 1: Chemical composition of iron nickel slag reduction.

Ni (%)	**Fe (%)**	**SiO_2 (%)**	**MgO (%)**	**CaO (%)**	**Al_2O_3 (%)**
0,12	11,38	50,51	28,64	0,48	3,44

Source: Data provided by the company.

4.2 For Solubilization

Table 2 shows the results of solubilization of metals present in the stack iron nickel slag.

Frame 2: NBR 10006:2004 - soluble - Inorganic Parameters.

Parameters	**Unit**	**NBR 10006:2004 – Sol**	**Reference Method**
Surfactantes	mg/L	0,5	SM21 5540 C
Alumínio	mg/L	0,2	SM21 3120 B
Prata	mg/L	0,05	SM21 3120 B
Arsênio	mg/L	0,01	SM21 3120 B mod
Cádmio	mg/L	0,005	SM21 3120 B
Cobre	mg/L	2	SM21 3120 B
Ferro	mg/L	0,3	SM21 3120 B
Mercúrio	mg/L	0,001	EPA 7470 A
Manganês	mg/L	0,1	SM21 3120 B
Sódio	mg/L	200	SM21 3120 B
Selênio	mg/L	0,01	SM21 3113 B
Zinco	mg/L	5	SM21 3120 B
Bário	mg/L	0,7	SM21 3120 B

Nitrato	mg/L	10	SM21 4500 NO_3F
Cromo Total	mg/L	0,05	SM21 3120 B
Fenóis Totais	mg/L	0,01	EPA 420 1
Cianetos	mg/L	0,07	SM21 4500-CN C/4500-CN F
Fluoretos	mg/L	1,5	SM21 4500-F C
Sulfato (expresso como SO_4)	mg/L	250	SM21 4500-SO_4^{2} E
Cloretos	mg/L	250	SM21 4500-Cr D

Source: Final Report of Studies n □ 37401/2008-0. Test for Waste Classification.

4.3 For Leaching

Table 3 shows the values of the chemical characterization of crude sample of slag reduction with the respective levels found in leaching test.

Frame 3: NBR 10005:2004 - Leachate - Parameters Inorganics.

Parameters	**Unit**	**NBR 10005:2004 – Lix**	**Reference Method**
Prata	mg/L	5	SM21 3120 B
Arsênio	mg/L	1	SM21 3120 B
Cádmio	mg/L	0,5	SM21 3120 B
Mercúrio	mg/L	0,1	EPA 7470 A
Chumbo	mg/L	1	SM21 3120 B
Selênio	mg/L	1	SM21 3120 B
Bário	mg/L	70	SM21 3120 B
Cromo Total	mg/L	5	SM21 3120 B
Fluoretos	mg/L	150	SM21 4500-F C

Source: Final Report of Studies n □ 37401/2008-0. Test for Waste Classification.

In this context, the analysis of slag FeNi Reduction parameters analyzed have appropriate concentration as indicated in Annex F and G of ABNT / NBR 10004:2004. Based on these results the classification of the waste is Class II type B - inert, indicating its use as aggregate in alternate paving without great risk of environmental contamination.

5 METHODOLOGY

We collected 300 kg of slag reduction Niquelândia and asphalt binder of Duque de Caxias do Rio de Janeiro (REDUC) and taken to the Laboratory of Bituminous Mixtures of Ligands and Military Institute of Engineering (IME) for the traditional characterization tests aggregate and binder under the following conditions:

- Households: grain size, density, real and apparent absorption, adhesion, and impact resistance.

- Asphalt Binder: penetration, relative density, viscosity, ductility, flash point, softening point and aging short term.

Were molded nine (9) body-of-proof 10 cm in diameter and 6 cm in height, recital 75 strokes per side, the methodology Marshall (DNER - ME 043/95), considering the following dash to the mixture: 60% slag iron nickel 30% crushed 1, 7% gravel and 3% cement, obtained by the method of trial and range of particle size following the "C" DNIT. Ranged up the asphalt binder content of 5%, 6% and 7%, and for each binder content was used three (3) body-of-evidence, and the mechanical tests of stability, and creep tensile strength.

6 RESULTS

The following are results of tests conducted on the materials collected.

6.1 Physical characteristics of the materials used

The samples collected in iron nickel slag, were conducted at the laboratory of asphalt binders and IME in Rio de Janeiro, which were performed characterization tests of aggregates and binders whose results are presented below. Tables 1 to 6, we will present some characteristics of the materials used on the dash prepared for this search.

Table 1. Assay granulated slag of iron nickel reduction

Sieve	**% passing**
3/8”	100
4	95
10	67
40	4
80	1
200	-

Table 2. Relative densities of the sample of iron slag Nickel reduction

Material	**Real density**	**Apparent Density**	**absorption**	**adhesiveness**
FeNi Slag	3,03	2,99	0,1%	not Satisfactory

Table 3. Assay particle size of the gravel 1

Sieve	**% Passing**
3/4”	100
1/2”	50
3/8”	19
4	3
10	2
40	1

Table 4. Relationship of the densities of gravel 1

Material	Real density	Apparent Density	absorption	adhesiveness	Tréton Impact
Gravel 1	2,73	2,67	1,5%	Satisfactory	72,45%

Table 5. Assay particle size of fine particles

Sieve	% Passing
4	100
10	75
40	39
80	20
200	6

Table 6. Relationship of the densities of fine particles

Material	Real density	Apparent Density	absorption	adhesiveness	Tréton Impact
Fine particles	2,86	2,79	-	Satisfactory	-

The characterization of asphalt binder is presented in Table 7, it is possible to conclude that it is an Pen 50/70, such that showed low susceptibility to short term aging, as evidenced by low variation in its softening point, among others.

Table 7. Characterization of asphalt binder

Testing		Temperature	Unit	Pen 50/70
Normal Penetration		25°	mm	57
Relative Density			g/cm³	1,02
Viscosity		130°	s	260
Viscosity		135°	s	205
Viscosity		140°	s	180,2
Viscosity		150°	s	115
Ductility		25°	cm	>100
Flash Point		-	°C	315
Softening Point (Ring and Ball)	Trace 1	-	°C	49,6
	Trace 2	-	°C	49,8
Assay of heat and air (RTFOT)		-	%	0,6
Softening Point (Ring and Ball) after RTFOT	Trace 1	-	°C	51,4
	Trace 2	-	°C	51,9

6.2 Trace mix type asphalt concrete with iron slag nickel Reduction

It was elaborated a trace of asphalt mix asphalt concrete type, using the Marshall method, binder type and Pen 50/70 REDUC, with density 1.01. The summary of the trace is presented in Table 8.

Table 8. Composition of concrete mix asphalt

Material	**Percentage (%)**	**Binder content (%)**		
FeNi Slag	60	5	6	7
Gravel 1	30			
Gravel	7			
Cement	3			

The following is presented in Figure 7 framing grain size has been possible in view of the characteristics of the slag aggregate FeNi, relative to the trace of the asphalt mixture prepared in range C of the standard asphalt concrete DNIT 031/2004 - ES.

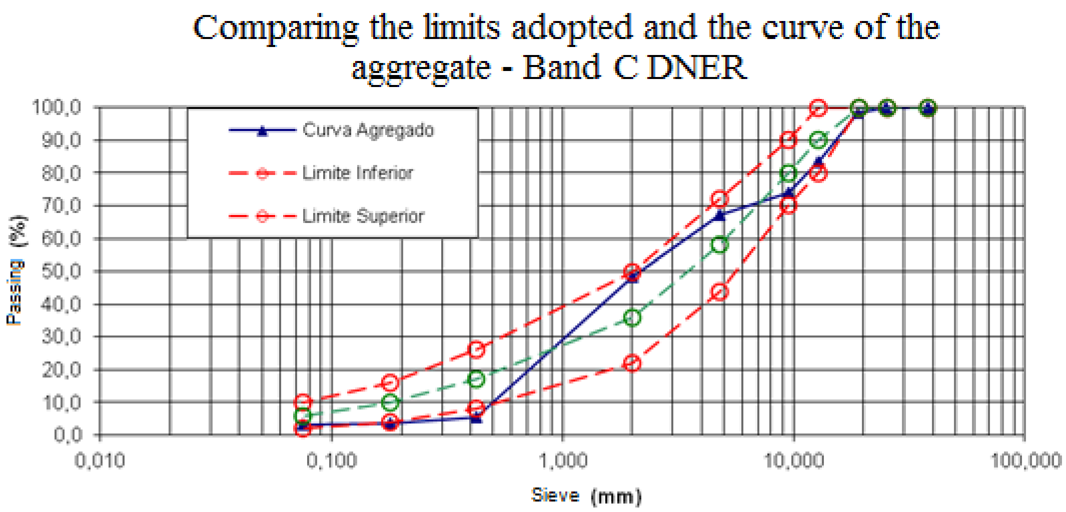

Figure 7 - Comparison between the limits adopted and the curve of the aggregate - Track C DNER

The results of volumetric and mechanical behavior of the bodies of the test piece obtained for this trait are shown in Table 9, which can be observed the high value of tensile strength (RT) stability and satisfactory void volume for the content of 6 % binder, being obtained the optimum binder content of 5.3%.

Table 9. Volumetry trace prepared with contents of 5%, 6% and 7% binder

Item	**Values**			**Limit**
Ligand concentration	5%	6%	7%	-
Apparent Density	2,43	2,47	2,45	-
Volume of Voids (%)	5,32	2,50	1,41	3 – 5
Volume of Mineral Aggregate – VAM (%)	17,07	17,68	18,09	-
Relationship Bitumen empty – RBV (%)	69,24	85,83	92,24	75 – 82
Theoretical Maximum Density	2,57	2,53	2,49	-
Minimum Stability (kgf) 75 golpes	539	708,56	394	500
Tensile strength by diametral compression static (MPa)	1,44	1,43	1,39	0,65

7 CONCLUSION

- Do you know what the reaction by hydration of calcium oxide is a key factor of expanding steelworks slag, a fact that limits its use in asphalt pavements. The results of the chemical characterization of iron nickel slag showed a small concentration of oxides of calcium, indicating that the material has low susceptibility to expansion and, consequently, pointing be an aggregate of promising use in flooring.
- Physical characterization traditional household iron slag nickel appeared satisfactory for the use of the mixture studied.
- It has been shown that the asphalt concrete made with aggregates of iron slag nickel showed physical and mechanical behavior consistent with traditional values, indicating that this is a suitable alternative to the use of this waste steel on asphalt mixtures.
- It was observed that the values of tensile strength (RT) diameter compression for this trait made with iron nickel slag had elevated and consistent with the results of asphalt concrete available in literatures.
- The search continues from the most modern testing methodology contained in Superpave, whose dosing process is based on the performance of asphalt mixture.

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