Characterization of silicon-manganese iron slag for employment in base and sub-base layers for highway

Filipe Batista Ribeiro[1], Bruno Guida Gouveia[2], Filipe Almeida Corrêa do Nascimento[3], Felipe Dias Costa[4], Marcelino Aurélio Vieira da Silva[5]

Department of Transportation Engineering, COPPE, Federal University of Rio de Janeiro, Brazil

Abstract— *The impact generated by the waste from the steel industry has prompted a series of discussions about the most environmentally friendly forms of final destination, such as reuse of byproducts resulting from the process of metal alloy generation. This is even more relevant after the environmental disaster in the state of Minas Gerais, Brazil, in 2015, when a tailings dam broke, causing widespread destruction of towns and pollution of rivers. To mitigate these problems, this paper presents the results of ongoing studies for the characterization of silicon-manganese iron slag and its potential application in mixtures with soil for the construction of base and subbase layers of highway pavement. Some methods used are traditional, such as measurement of granulometry, bulk density, absorption and Los Angeles abrasion. Others have more recently been applied to characterize aggregates, like scanning electron microscopy (SEM) and aggregate image measurement (AIM). Complementarily, due to the vitreous appearance the slag, ductility results are reported, obtained according to degradation after Proctor compaction testing and determination of shock loss in a Treton apparatus. Finally, the results already obtained, along with those of studies with the same material for rail ballast and asphalt concrete, show that silicon-manganese iron slag presents geotechnical properties compatible with those established in the specifications for use in base and subbase layers of highways.*

Keywords— *base and subbase layers, highway, pavement, silicon-manganese iron slag.*

I. INTRODUCTION

Road construction is an activity in which natural resources are more often used in comparison with other sectors of civil engineering. Large amounts of natural materials such as gravel, rock and sand are used to build and repair roads and highways. In this sense, sustainable development requires more efficient management of waste for preservation of the environment [1].

In recent years, investment in solutions for industrial waste recycling has been intensifying in many countries. Several companies have been investigating technology to reuse industrial waste to enhance the efficiency of production systems [2].

This article characterizes the silicon-manganese iron slag produced in electric furnaces for use in road pavement layers, in the region of the state of Minas Gerais (Brazil) known as the "Iron Quadrilateral", composed of the municipalities of Santa Bárbara, Mariana, Ouro Preto, Congonhas and Itabirito. This is done by reporting technical parameters obtained through testing, as defined by the current standards from Brazilian and foreign institutes

II. LITERATURE REVIEW

Initially, some definitions should be described. According to Law 12,305 [3], solid waste is material that still has some value for use, through available and economically feasible technology, even for a purpose different from that originally planned. Tailings, on the other hand, are characterized as solid wastes which, after exhausting all possibilities of treatment and recovery by available and economically feasible technological processes, present no possibility other than the final environmentally appropriate disposal. Therefore, using the definition of [4], which treats slag as solid waste from the melting of metals or from the combustion of certain materials, it can be concluded that the elements resulting from steel processing can sometimes be classified as waste and at others as tailings. The waste material analyzed here is

slag, which results from a process where the combination of metal and non-metallic compounds is heated to the melting point. Some efforts have been made to reuse it, in particular as layers for road paving.

Many companies are engaged in turning materials classified as byproducts - compounds produced as a waste during the production process – into co-products, that is, materials characterized as desirable secondary goods that are generated during the manufacturing process and can be sold or reused profitably [5]. Co-products of the steel industry have been studied extensively by the world's largest steel producer, China Steel Corporation [6]. The applications vary according to the generation of slag, but the residues are basically used in the composition of cement and concrete, bricks, road construction and landfill cover [7]. In Europe, besides these uses, there are also applications in hydraulic engineering, fertilizers, and internal use in metallurgical processes [8]. Studies in Germany for use of byproducts of steel production as raw materials in road construction [9] have found technical advantages such as avoidance of emission of pollutants and climate impact by use of slag in road construction. In France, [10], in a doctoral thesis, studied slag from the production of silicon-manganese alloys for various potential uses. In Australia and Asia, interesting options have been tested, such as for making rock wool, drains for groundwater treatment and geopolymers [11]. In Japan, slag has also been used for highway paving, cement, soil stabilization and concrete aggregates, among others [12]. In the United States, slag has also been used as railroad ballast, for levee construction, erosion control and containment structures, among other solutions [13].

In Brazil, studies such as those by [14], [15], [16], [17] and [18] have shown possible uses as artificial aggregate in engineering structures such as highways and railroads, as well as in the production of cement.

According to the [19], pavement is a structure built after the embankment and destined to resist and distribute to the subgrade the vertical forces generated by traffic; improve rolling conditions for convenience and safety; and resist the horizontal stresses acting on it, making the rolling surface more durable [19]. In this paper, the objective is to characterize silicon-manganese iron slag to verify, in addition to other parameters, its resistance, i.e., the ability of the slag to compose the pavement structure to resist the loads from traffic applied on it.

[15] reported mechanical characteristics of asphalt mixtures using manganese ferroalloy slag from the Simões Filho region (Bahia) as an aggregate. Initially, the slag was characterized physically, mechanically and chemically, as described in the specification standards of the National Department of Roads and Highways (DNER) in the standards DNER-ME 260/94 and DNER-ME 262/94. As complements, scanning electron microscopy (SEM) and X-ray dispersive energy (EDS) tests were carried out to determine the shape and chemical composition of the materials. In addition, the environmental impacts were analyzed through solubility and leaching tests. Finally, due to the known problem of slag expansion, testing was performed according to the Pennsylvania Test Material standard (PTM 130). Once characterized, the material was mixed with crushed stone powder and CAP 50/60 (now CAP 50/70) for the manufacture of hot-rolled bituminous concrete. In addition to the test specimens produced in the laboratory, samples were analyzed in the field by using the mixture on Avenida Dom João VI, in collaboration with the Salvador municipal government. The technical results validated the use of manganese ferroalloy slag for asphalt coating, and environmental tests showed that the slag is classified as Class II - not inert.

[17] carried out the physical, mechanical, chemical, mineralogical, environmental and electrical characterization of silicon-manganese iron slag for application as an aggregate in railway paving in state of Minas Gerais. The material analyzed presented higher values than the minimum limits prescribed by national and international technical standards, showing that silicon-manganese iron slag is a good substitute for the rock materials used for rail ballast.

The consolidation of the use of slag as a co-product is shown through the standards created to standardize its use: NBR 5735/1991 - Portland cement from blast furnace; DNIT-113/2009 - Road Paving - Artificial Aggregate - Evaluation of the expansion potential of steel slag; DNIT 114/2009 and DNIT 115/2009, which deal with the use of slag in the base and subbase structures; DNIT 406/2017 - Road paving – Base granulometrically stabilized with Açobrita®; and DNIT 407/2017 - Road paving - Subbase stabilized granulometrically with Açobrita®.

The silicon-manganese iron slag analyzed here is produced in the region of the city of Barbacena, Minas Gerais, located near to the "Iron Quadrilateral". It is the residue of a ferroalloy, an essential input used in the steel industry, both in the basic processes and in refined aggregation to produce special steels [17]. Ferroalloys are iron alloys with other metals, in which the content of other metals is higher than the iron content. The purpose is to impart certain properties to the steel. The other metals used are nickel, manganese, chromium, tungsten, niobium and titanium. Manganese, added in the form of ferroalloy, assists in the refinement of the grain structure, increasing the

mechanical strength and improving the temperability and the ductility of the steel [20]. The slag is generated during the production of the ferroalloy in submerged arc electric furnaces. Removal of the slag is intended to remove impurities from the furnace. It occurs throughout the process, since during the smelting and refining steps, some of the scarified impurities tend to return to the alloy [17]. There are two types of slag formed by the described production processes: rich slag, which is acidic, has high Mn content (greater than 40%); and poor slag, which is basic, has low manganese content (MnO <20%) and about 30% Si. The latter is produced during the upgrading the standard alloy by adding silicon waste, and is discarded at the end of the ferroalloy production process [17].

This study presents technical parameters to evaluate the possibilities of using silicon-manganese iron slag in road pavement structures.

III.   METHODOLOGY

The material studied is produced by a steel company located in the city of Barbacena, state of Minas Gerais, Brazil. Currently, this residue is stored in piles at the mill, and comes from the process of making ferroalloy. To perform the experiments, samples were collected in sufficient quantities for the physical, mechanical and chemical characterization in the laboratories of the Military Institute of Engineering (IME), in the city of Rio de Janeiro.

For the evaluation of the material, the main methods specified in Brazilian standards for validation of employment in road structures were applied, such as particle size analysis (DNER-ME 083/98), determination of absorption and bulk density (DNER-ME 081/98), and Los Angeles abrasion determination (DNER-ME 035/98). These tests were carried out at the Soil Laboratory of the Military Engineering Institute. In addition, complementary tests were carried out, such as mineralogical composition through energy dispersive spectroscopy (EDS) and scanning electron microscopy (SEM), both at the Materials Laboratory of the IME. Shape, texture and sphericity were determined by an aggregate image measurement system (AIMS) in Laboratory of Federal University of Rio de Janeiro. Due to the vitreous aspect of the material, tests of the degradation index after Proctor compaction (DNER-ME 398/99) and determination of shock loss in a Treton apparatus (DNER-ME 399/99) were performed at the IME Pavement Laboratory.

3.1 Granulometry

Granulometry is the size and weight distribution of the particles that compose an aggregate. This distribution is ascertained when the sample is passed through a series of sieves, whose meshes are standardized, and the result of this process is represented graphically through the granulometric curve. This curve is then compared with intervals called sieve ranges, which have the objective of determining the resistance through interlocking of the grains. In the present study, the material was processed using the standard series of sieves: 19 mm, 9.5 mm, 4.8 mm, 2.4 mm, 1.2 mm, 0.60 mm, 0.30 mm and 0.150. Due to the crushing cost, the material had been produced with large aggregate diameters, since the purpose of the company is only to store this material in piles. Equations (1) and (2) were used in this test, as shown below:

$$\%Retained = \frac{Retained\ weight}{Total\ weight\ of\ sample} \qquad (1)$$

$$\%Passed = 100\% - \%\ Retained\ Acumuled \quad (2)$$

3.2 Bulk density of coarse aggregate and absorption

The bulk density of the aggregate, obtained by the relation between the weight of the dry aggregate and its volume, is the parameter used as reference for the weight of the material, to be used either in asphalt mixtures or in base and subbase layers. In turn, absorption is determined by the increase in weight of the aggregate due to the filling of its permeable pores (voids) by water, allowing analyzing the porosity of the aggregate, both to verify its resistance and to measure the consumption of binder (e.g., paving asphalt cement), when used as aggregate in asphalt mixtures.

According to standard DNER-ME 081/98, equation (3) defines the bulk density:

$$D_b = \frac{W_s}{W_h - v} \qquad (3)$$

D_b is bulk density;

W_s is weight, in air, of the aggregate dried in drying oven, in *g*;

W_h is weight, in air, of the aggregate in the dry surface saturated condition, in *g*;

v is the scale reading corresponding to the submerged aggregate - hydrostatic weight, in *g*.

For Absorption, the expression (4) used is:

$$a = \frac{W_h - W_s}{W_s}\ x\ 100 \qquad (4)$$

a is absorption, in percentage.

3.3 Determination of Los Angeles Abrasion Value

The Los Angeles abrasion is a measure of the resistance to surface wear of the aggregate grains when subjected to friction. Thus, the assay measures the aggregate's ability to remain unchanged when handled. The test consists of depositing a certain weight of aggregate, with known

granulometry, inside a cylindrical drum together with cast iron balls.

The drum is then revolved at the rate indicated in the standard, and after being removed from the drum, the material is washed through a 1.7 mm sieve and then dried in an oven. Finally, the dried sample is weighed.

For this study, Grade A was used the standard DNER-ME 035/98 - Determination of Los Angeles Abrasion Value.

3.4 Mineralogical Analysis

For mineralogical analysis, X-ray dispersive spectroscopy (EDS) was used, consisting of microanalysis to obtain qualitative and quantitative (in micrometers) chemical information, obtained by the detection of X-rays resulting from the interaction between the primary beam and the sample. In EDS analysis, a semiconductor material is used to detect X-rays and a multi-channel analyzer, which converts X-ray energy into an electronic output, resulting in a spectrum representative of the chemical analysis of the sample. The equipment used was the a JEOL 5800LV.

3.5 Scanning Electron Microscope (SEM)

For the analysis of the microstructure, scanning electron microscopy (SEM) was used, in which images with up to 8000x magnification were generated. The results of this test allow analyzing the shape and size of the grains and voids, as well as their arrangement on the surface of the sample. The use of EDS together with MEV is of great importance in the petrographic characterization and petrological study in geosciences, since the first one allows the identification of the elements that compose the sample and the second provides clear images of the microstructure

3.6 Aggregate Imaging System (AIMS)

The aggregate imaging system (AIMS) was developed to capture images and analyze the shape of a wide range of aggregate types and sizes, including those used in asphalt mixes, hydraulic cement concrete, and unbound layers of pavements [21]. This system is used to analyze the shape, texture and angularity of aggregates, leading to a new aggregate classification based on the distribution of the shape characteristics.

Angularity (or roundness) measures the difference between a particle's radius in a certain direction and that of an equivalent ellipse. The equivalent ellipse has the same aspect ratio as the particle, but it has no angularity. Sphericity – or particle form [22], or shape [23] – is the parameter that classifies the aggregates as by their shape. This is a dimensionless parameter that varies between 0 and 1, whereby aggregates with indexes close to 1 have optimal sphericity and aggregates with indexes close to 0 have low sphericity, that is, they are more layered than spherical [24]. Surface texture is used to describe the surface irregularity at a scale that is too small to affect the overall shape or angularity [23].

Table 1 shows the limit values and classification for aggregate shape properties:

Table 1: Limit values and Classification for Aggregate Shape Properties. Adapted from [28]

Property	Limit values / Classification				
Sphericity (coarse aggregate)	<0,6 Flat Elongated	0,6 - 0,7 Low sphericity	0,7 - 0,8 Moderate sphericity	> 0,8 High sphericity	- -
Angularity (fine and coarse	< 2100 Rounded	2100 - 4000 Sub Rounded	4000 - 5400 Sub Angular	> 5400 Angular	- - -
Texture (coarse aggregate)	< 165 Polished	165 - 275 Smooth	275 - 350 Low Roughness	350 - 460 Moderate Roughness	> 460 High Roughness

Degradation index after Proctor compaction and shock loss in Treton equipment

The Proctor compaction degradation index (ID_p) and the shock loss determination in the Treton device are used analyze the characteristics regarding toughness, abrasion resistance and hardness of aggregates. The indications of these tests as well as limit values adopted for them were obtained from a study conducted by the Road Research Institute (IPR-DNER), as reported by [25]. Although the value found for the silicon-manganese iron slag was satisfactory for the abrasion test, we considered it important to validate the results by other analyses due to the vitreous aspect of part of the material, and its microstructure similar to cleaved planes.

The Proctor compaction degradation index is measured by washing and oven drying the sample at a temperature of 100 to 105 °C and then determining the weight of the particles from specimens used in the Proctor compaction test. After 24 hours, the material is passed through the same standard series of sieves, and weights the material retained are measured. The index is calculated by expression (5):

$$ID_p = \frac{\sum D}{4} \qquad (5)$$

ID_p is Index of Degradation

D is difference between Avarage of samples and Original Granulometry

Shock resistance is an index used for the differentiation of materials used as ballast in train tracks, since this material is subject to large forces during the passage of the train. Since this work is aimed at evaluating the use of silicon-manganese iron slag in road paving, the reference value for this test presented by the Road Research Institute (IPR) for validation of material is used. Using the Treton apparatus, about 20 grains make up the sample, whose diameter is between 16 and 19 mm. They are subjected to 10 strikes by a hammer weighing 16 kg at a height of 380 mm. The loss of mass is calculated with equation (6):

$$T = \frac{M_r}{M_i} x 100 \qquad 6)$$

T is loss to shock (Treton), expressed as a percentage;

M_r is weight of the material retained in the sieve 1.7mm, in g;

M_i is initial weight of the material, in g.

IV.   RESULTS

4.1 Granulometry

As a reference, "Range A" of the Brazilian National Department of Transport Infrastructure - DNIT (Granulometrically Stabilized Base - DNIT 141/2010) was used. This is shown in the graphs of Figure 1 by the two continuous lines, called DNIT Max and DNIT Min. As can be observed, the composition of the material presents predominantly large grains, consistent with the policy adopted by the company generating the waste of reducing cost of crushing. If a form of grain reduction is not feasible, an option for the use of this material would be for mixture with soil. The results are shown in Figure 1.
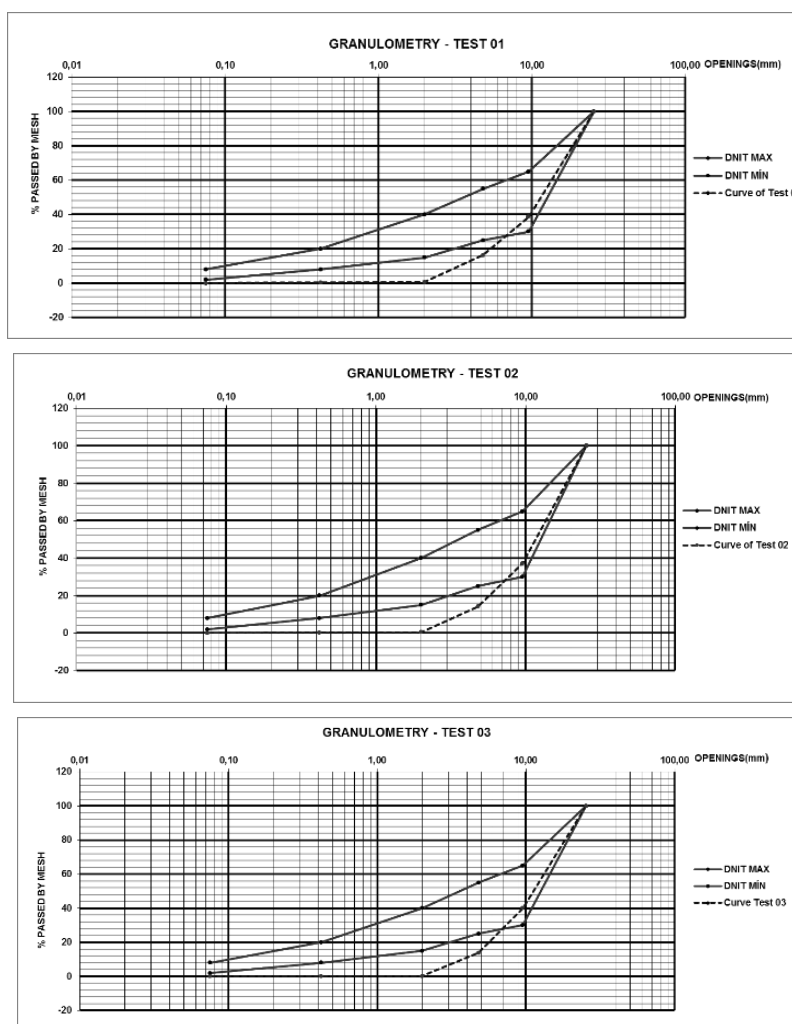

Fig. 1 – Result of Granulometry of Sample 01, 02 and 03

4.3 Bulk density of coarse aggregate and absorption

The density of the aggregate found was 2.94 g / cm³ and the absorption was 0.44%. This density is very close to that (2.96 g / cm³) of the silicon-manganese iron slag studied by [17], whose material was obtained from the same company generating the slag analyzed here, but at a mill located in another city in Minas Gerais. The value is also close (2.92 g / cm³ for granulometry from 0 to 3/8 ") to that found by [15], who analyzed manganese ferroalloy slag for use in asphalt coating.

Finally, when compared with granite gneisses from the state of Rio de Janeiro analyzed by [26], where values of 2.62 and 2.64 g / cm³ were found, the material has a value higher than natural aggregate. However, silicon-manganese iron slag has lower density when compared to steel slag, whose values are above 3.0 g / cm³, according to [14].

For absorption, the values found by [17] and [15] were higher than 1.0%.

3.7 Determination of Los Angeles Abrasion Value

The value of 25.53% for abrasion is within the limits established by standards DNIT 141/10 - Granulometrically stabilized base, DNIT 406/17 – Base granulometrically stabilized with Açobrita® and DNIT 407/17 - Subbase granulometrically stabilized with Açobrita®, all of which define 55% as the maximum abrasion for an aggregate to be used in pavement layers. In addition, silicon-manganese iron slag is also suitable according to DNIT 115/09 – Base granulometrically stabilized with steel slag - Acerita® and DNIT 114/09 – Subbase granulometrically with steel slag - Acerita®, which define the abrasion limit as 40%.

3.8 Mineralogical Analysis

There are two types of slag formed by the silicon-manganese iron (FeSiMn) production processes. The first is rich slag, which is acidic, has high Mn content (above 40%) and very low phosphorus content, being recyclable and reused as an input in FeSiMn production. This slag is subject to vitrification, which decreases its resistance and makes it dangerous to handle. The second is poor slag, which is basic, has a low manganese content (MnO <20%) and about 30% Si, produced by upgrading the standard alloy by adding silicon waste from ferrosilicon production, while that from ferroalloy production is discarded [27].

Due to the heterogeneity of the material, the EDS test was performed in two distinct regions of the aggregate, which are indicated by the two rectangles in Figure 5. According to the result obtained, the main elements that form the silicon-manganese iron slag are carbon, oxygen and silicon, followed by calcium, manganese and aluminum (Figure 2). Thermogravimetric analysis (TGA) was

performed to ascertain how these elements are grouped into compounds, and thus to define more clearly the mineralogical composition of the slag.
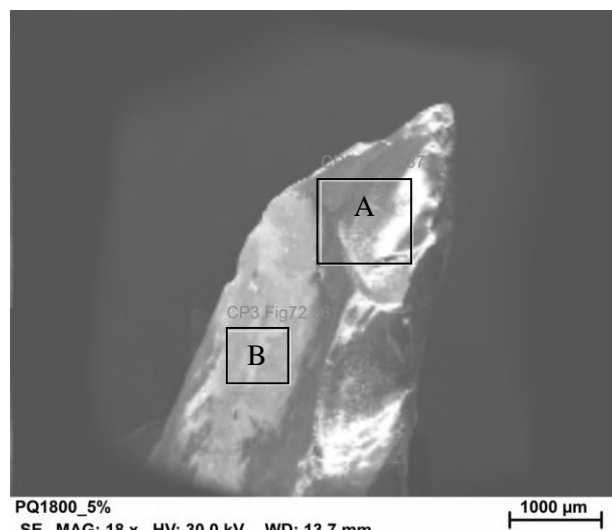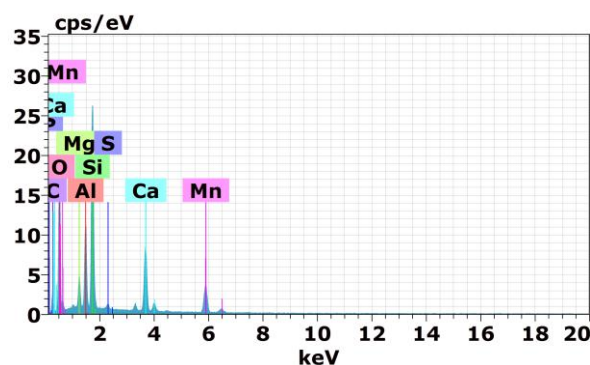

Fig. 2.a: EDS test image result – two areas analyzed

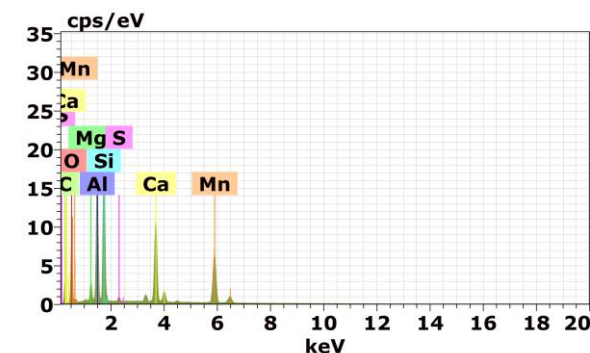

Fig. 2.b: Mineralogical Analysis area A

Fig. 2.c: Mineralogical Analysis area B

The mineralogical determination is relevant since according to Oliveira (2013), the main problem in the use of slag in pavement is its expansive characteristics, due mainly to the hydration of free lime (CaO) and magnesium oxide (MgO) and the corrosion and oxidation of the residual iron, generating internal stresses that cause cracking and even fragmentation of the material, caused by expansion. Therefore, the determination of the quantity of these

elements helps to predict the potential for expansion of the material.

Since [15] also used silicon-manganese iron slag, as referenced by [17], it is possible to adopt the value found according to PTM 130/78 (Pennsylvania Test Method) for the material under study. As can be seen in the graph below, the expansion can be considered to be 0%.

On the possible environmental impact of silicon-manganese iron slag disposal, [17] presented an official letter from Brazilian Institute of Environment (IBAMA) approving the use of silicon-manganese iron as slag as railway ballast. Also, in this work, the silicon-manganese iron slag sample was classified as Class II A (non-hazardous - not inert) because it had solubilized aluminum content above the maximum allowable limit.

3.9 Scanning Electron Microscope (SEM)

The slag studied has distinct characteristics from electric arc furnace slag. The main differences are the greenish color, smooth surface, glassy aspect and the small number of fines. Some of these characteristics can be clearly noticed when comparing images of the microstructures of the two materials, according to the following figures. The quantity of voids is markedly lower in the silicon-manganese iron slag, explaining the more compact appearance of the material. In addition, the material is formed by layers (structure similar to cleavage planes), suggesting that the rupture occurs by shearing. Figure 3 shows the difference between arc furnace slag and silicon-manganese iron slag.
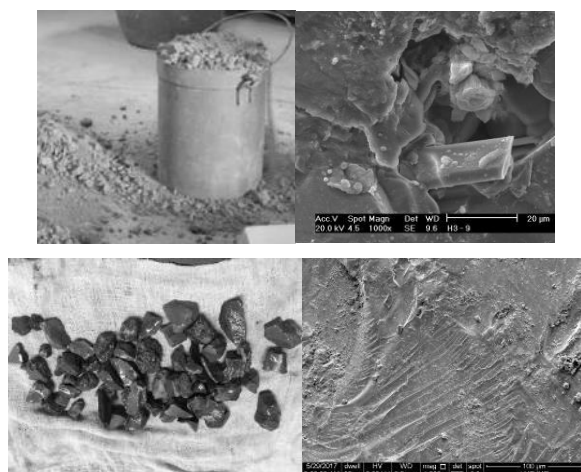

Fig. 3: Macro and microstructure of steel slag (upper), RODRIGUES, 2007 (1000x); Macro and microstructure of silicon-manganese iron slag (lower) (1000x).

### 3.10 Aggregate Imaging System (AIMS)

Graphs 1.a, 1.b and 1.c below show the aggregates shape properties. In the legend, the word *Escoria* means slag.

According to Graph (1.a), the material, in general, can be classified as subrounded, since more than 90% present angularity index greater than 2100, where 52% is classified as moderate.

According to technical specification from the Department of Roadways of São Paulo (ET-DE-P00/008) and the national standard (DNER-ME086/94), the sphericity (shape index) of aggregate should be equal to or greater than 0.50. As can be seen in Graph (1.b), more than 90% of the samples meet this requirement, the exception being the aggregate with 4.75 mm. In addition, the standard recommends that less than 10% should be of lamellar particles, so the aggregate analyzed also meets this specification.
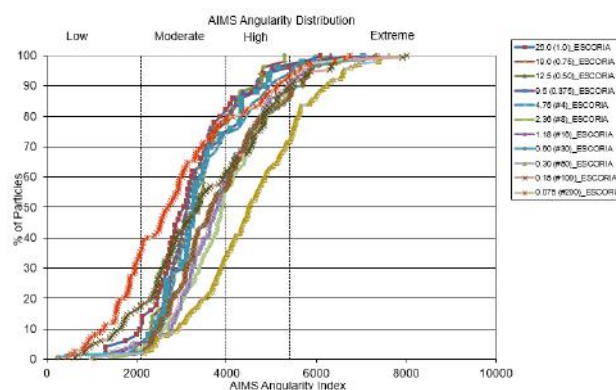
GRAPH 1.a: Angularity Distribuition
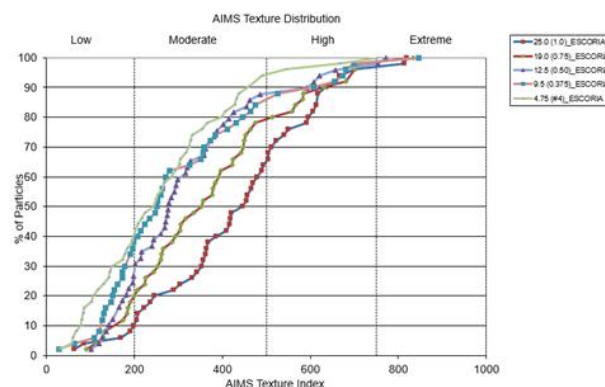
GRAPH 1.b: Sphericity Distribuition
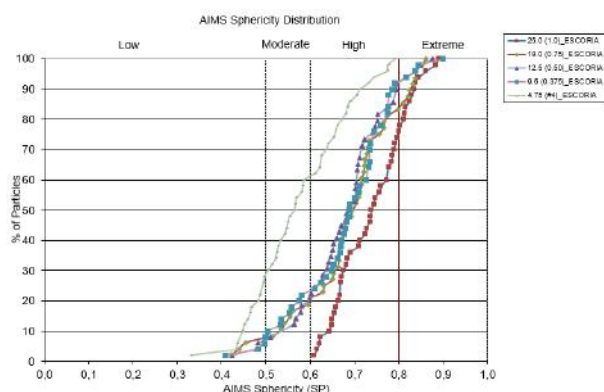
GRAPH 1.c: Texture Distribuition

The texture (Graph 1.c) is closely linked to the frictional force, and the greater the surface roughness, the greater the resistance to permanent deformation, since the frictional force between the grains will be higher. A granular material is typically rougher after crushing [26]. The results show that more than 70% is greater than 200, and 55% is classified as moderate.

Some studies, such as [26] and [28], have been performed to establish reference parameters for angularity and texture, which are linked to resistance.

4.8 Degradation index after Proctor compaction and shock loss in Treton equipment

The degradation index test was performed after measuring the California Bearing Ratio (CBR) test, the pellet being subsequently passed back through the sieves used for sample separation. As a result, an IDp of 0.26 was obtained, that is, the material degraded in the sieves with larger diameters was retained in the smaller sieves. The results are reported in Table 1:

Table 2: Summary of the results of the ID_p.

Sieves	% Passed						
	Original Granulometry	Granulometry after compaction					
		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
19mm	68	83	78	79	84	86	82
12,5mm	64	68	63	67	69	71	68
9mm	62	59	54	57	60	61	58
nº 4	60	48	44	46	48	50	47	-
Sum D							
							IDp

Based on the Methods for Testing Mechanical Characteristics and Values for Acceptance of Aggregates of [29], whose limit for ID_p is equal to 6, it is possible to affirm that the material is acceptable.
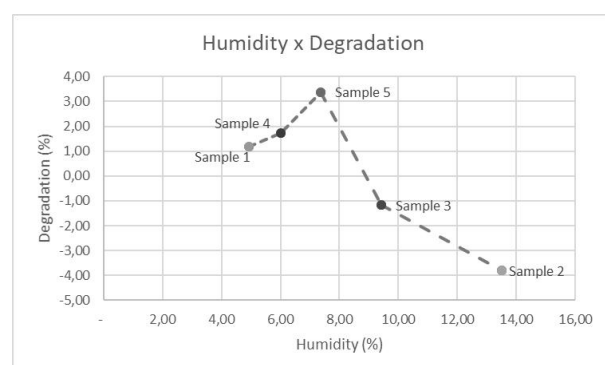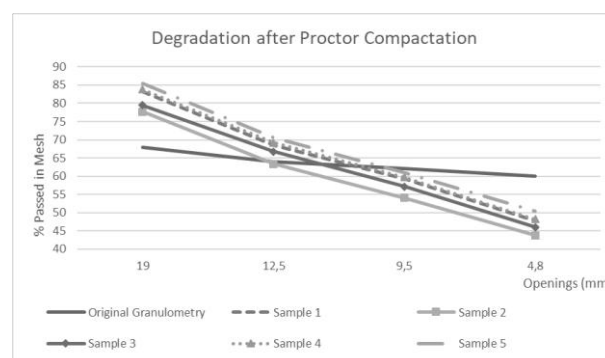
Graph 2 above shows that, in a relatively proportional way among the samples, the coarse aggregate (between 19 mm and 12.5 mm) assumed smaller grain sizes, from 12.5 mm to 4.8 mm. According to Graph 3, the greatest degradations occurred in the sample with optimal moisture (Sample 5), followed by the samples with lower moisture (Samples 1 and 4), and finally the smallest weight losses occurred in the larger aggregates (Samples 2 and 3). It is interesting to observe that the curve defined by the comparison Moisture x Degradation (Graph 5) presents a shape similar to the compaction curve (Procter moisture content x Maximum density). Finally, the greatest degradation is precisely in the ideal conditions for use in pavement. Therefore, it is prudent to take the necessary precautions to protect the grains when compaction is performed.

GRAPH 2: The graphic (upper) shows the granulometry of aggregates after Proctor compaction. The second graph (lower), shows the relationship between humidity and degradation.

A similar analysis was performed about geotechnical characterization of silico manganese slag for civil engineering applications, where [30] presented the results of silicon-manganese slag granulometry before and after compaction. In that study, the percentage of large particles decreased from 15% to 0%, the sand increased from 84% to 97%, and fines from 1% to 3%.

For the Treton test, shock loss was 8.88%. As reference, the value of 60% is the maximum admissible loss, described by the Institute of Road Research [29] in its Test Methods for determination of mechanical characteristics of aggregates and acceptance values, in the book Asphalt Paving: Basic Training for Engineers [25]. The material tested here is thus acceptable for use in pavements.

V. CONCLUSION

This purpose of this study was to characterize silicon-manganese iron slag, using methods, standards and tests, to analyze the technical feasibility of using this material in road pavement layers.

The granulometry has predominantly coarse grains, so the addition of soil is advantageous to adjust the slag grain size. Bulk density values are similar to those found by others authors, and higher than natural coarse aggregates. The Los Angeles abrasion value is according Brazilian standards for use in base and subbase layers. Regarding mineralogical analysis, the silicon-manganese iron slag is mostly composed of carbon, oxygen and silica, followed by lesser quantities of calcium, manganese and aluminum. Expansion, according [15], is zero. [17] classified the material as Class II A (non-hazardous- not inert). Scanning electron microscopy revealed the structure is more compact than steel slag, and is similar regarding cleavage planes. The AIMS analysis indicates the angularity is rounded; the sphericity is according to the values of Brazilian standard for use in base and subbase layers; and the texture is classified as moderate. Regarding the degradation index after Proctor compaction and shock loss measured by the Treton equipment, both results for silicon-manganese iron slag are within the parameters defined by the Brazilian Institute of Road Research for use in pavement structures.

Finally, in view of the results presented by the tests and methods used, the silicon-manganese iron slag is feasible for use to pave roads.

ACKNOWLEDGEMENTS

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