# COMPARATIVE STUDY ON THE RESISTANCE OF PORTLAND CEMENT CONCRETE USING VARIOUS TYPES OF LATERITE FROM SÃO LUÍS ISLAND IN THE STATE OF MARANHÃO, BRAZIL

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**Abstract** – On the island of São Luís in Maranhão, Brazil, four types of aggregate rock materials designated as laterite have historically been used as aggregates in civil construction projects. This study is unique because it uses laterite developed in sedimentary rocks with ferruginous cement as an aggregate (rocky material). Additionally, this material can be used to supply all aggregates (coarse and fine), whereas in other studies, fine aggregates were generally found in washed sand from rivers. There was also a fifth type of laterite, called colluvium, that was disregarded in this study because it contains large amounts of fine material. A summary of the technological tests for the aggregates, resistance to simple compression, the slump test, and the cement consumption are following showed. The sedimentary rocks used to produce the aggregates in São Luís are primarily composed of subangular and high-sphericity quartz grains cemented by several iron oxides. When crushed, the above sedimentary rock forms aggregates with a cubic form and granulometry close to the Fuller curve theory, which enables high resistance when shaped in specimens of 1:4 and 1:6 using water/cement ratios of 0.45 and 0.50, respectively. The existing petrographics four types in the in distinct deposits showed that the concrete aggregate, the Ferruginous conglomerate type of laterite, obtained from the petrographic analysis behave better physically and mechanically when molded into specimens with 28 days of healing and with different strokes and water/cement ratios. Values of 33.97–34.25 MPa were determined for the simple compressive strength.

**Keywords -** lateritic concrete strength; physical, chemical, mechanical, and geological properties of lateritic aggregate; sedimentary rock with lateritic ferruginous cement; laterite and concrete uses in Portland cement; lateritic aggregate.

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## 1. INTRODUCTION

On the island of São Luís in Maranhão, Brazil, four types of stone materials, known as laterites, have historically been used as aggregates in civil construction projects. Laterite is the most abundant stone material in this area. In this study, we identified four types of sedimentary rocks cemented by ferruginous oxides, called laterites, that contain an appropriate silica–sesquioxide relationship according to DNER (National Department of Highways) specifications.

New world social paradigms have caused governments to develop infrastructure policies that prioritize the use of stone materials by their populations and have consequently highlighted the need to develop, with the support of technical and scientific knowledge, new materials that can participate in the production chain. In this regard, this study provides technical and scientific support for such a case.

The different types of laterite from São Luís, Maranhão, Brazil, are manually broken (crushed) with the aid of sledgehammers, mixed in the same lot, transported, and sold as building materials. Thus, all four types of laterite, which have different features and potential uses, can be found in the same lot of stone material. Currently, the term "lateritic concrete" is widely accepted as a concrete using lateritic concretions to replace conventional aggregate.

Geomorphologically, Fig. 1 shows that the island of São Luís has five distinct elevation zones, including high elevations of greater than 60 m, areas with significant undulations, areas that are often affected/carved by rivers that drain to the coast, and alluvial plains that are periodically flooded by the sea.

In Brazil, research on applying laterite to civil engineering projects has been conducted to characterize laterite concrete, which creates a secondary objective of determining the intrinsic characteristics of laterite aggregates.

Other studies have used laterite to supply only the coarse aggregate and have used washed river sand for the fine aggregate. However, in this study, we did not use any foreign stone material to produce laterite.

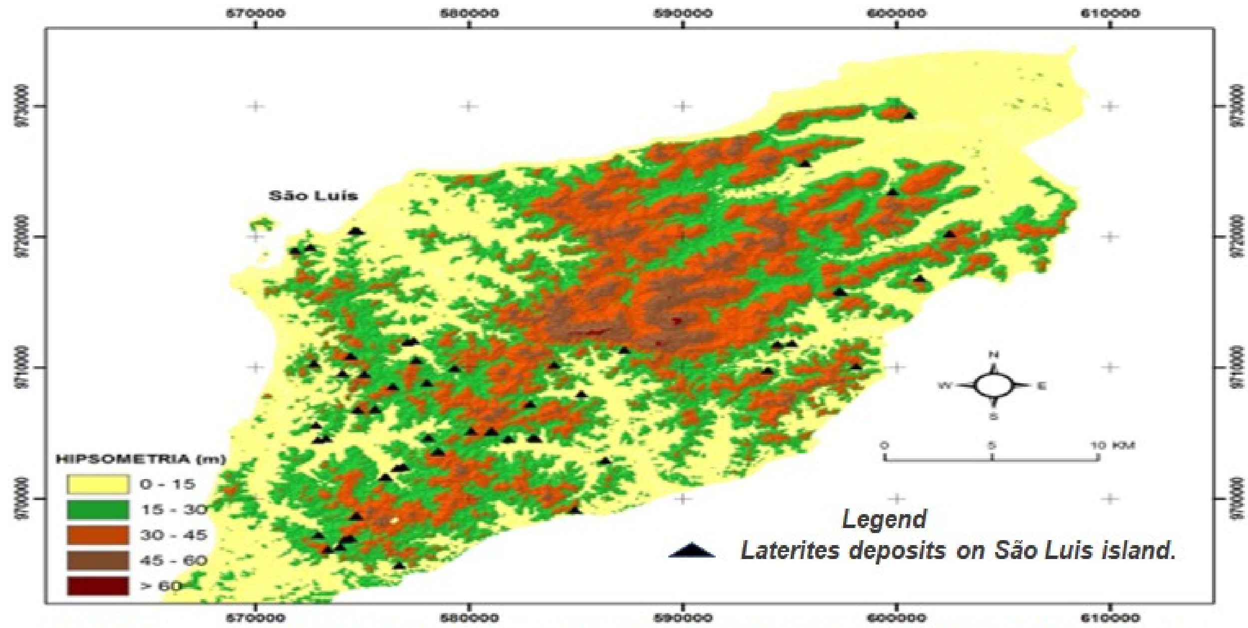


Figure 1 Hypsometric map of the study area indicating the elevation zones and the locations of others ferruginous laterite deposits (black triangles).

The mining of laterite in São Luís is not directed for specific purposes, i.e., high-quality aggregates are employed in construction projects that request lower-quality aggregates, thereby requiring the separation of these materials into the different types identified in this work since each type of identified stone material has its own specific characteristics, including particle size (granulometric curve), oxide content, hydration, and compressive resistance.

There is an extensive body of data and observations on laterite that have been carried out by different types of professionals, e.g., geologists, soil scientists, biologists, chemists, engineers, geographers, and builders.

Obviously, the work and the attention of each of these professionals are focused and targeted on areas that do not always coincide. The different approaches are a reflection of the interests of each field of expertise.

## 2. MARANHÃO LOCATION

### 2.1. Location of the studied materials

The area of greatest interest, where the field studies were concentrated, occupies 14,500 $m^2$ on the island of São Luís in Maranhão, Brazil. The island of São Luís covers an area of 905 $km^2$ and is limited by the lower Bacanga River to the northwest and the Bay of St. Mark to the west, where the city of São Luís, the state capital of Maranhão, is located.

In the region of São Luís, state of Maranhão, according to the geological map at a scale of 1:250,000, Fig. 2**,** the materials involved in the laterization process include the Barreiras Group with Tertiary lithologies and colluvial deposits from the latest Quaternary. The Barreiras Group laterites are the major producer of aggregate materials for Portland cement concrete**.**

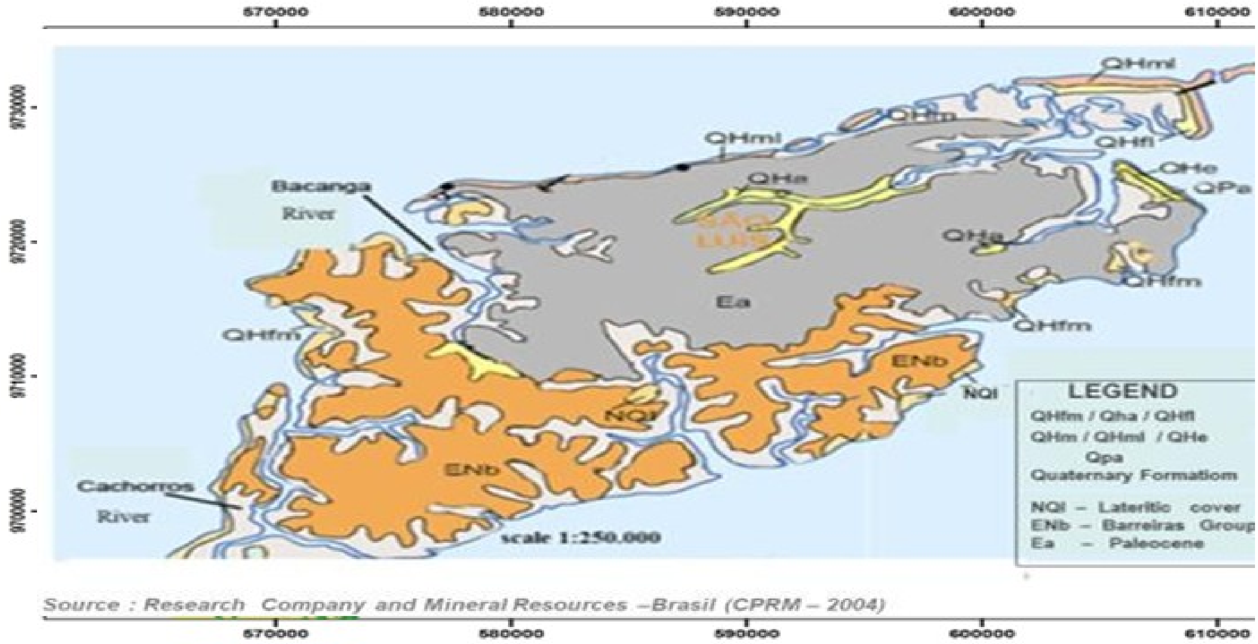


Figure 2. Geological map of the island of São Luís.

## 3. MATERIALS, ROCK TYPES, RESULTS, METHODOLOGY AND DISCUSSION

### 3.1. Location of the studied materials

Four types of laterite samples are presented below, reflecting the pattern of behavior of the rock types/petrography. These types are defined with the local names in parentheses

### 3.1.1. Medium Grained Ferruginous Sandstone (Local name: Gran Fina Preta – Black Thin Gran): sample 1- (ABNT-NBR-7389 – Microscopic analysis of petrographic polarized light test method)

This petrographic type consists of common quartz grains, undulating extinction, and a polycrystalline texture with a particle size ranging from coarse to very fine, with medium sand as the modal value and no gravel. Sorting ranges from moderate to good, and subangular rounding is common, but well-rounded, high-sphericity grains are dominant. The cement has a hematite and limonite composition with a grayish black color. Fig. 3 shows a photomicrograph obtained via a polarized light microscope illustrating the interaction between the rocky matrix and the rock cement.

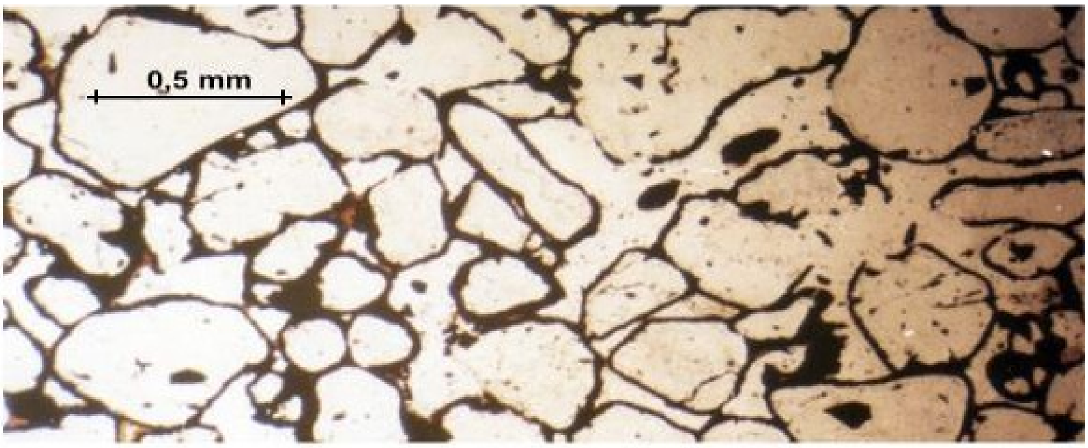


Figure 3. Photomicrograph of the medium-grained ferruginous sandstone and matrix/cement mixture, which has a medium sand size as the modal value, moderate to good sorting and high-sphericity grains with ferruginous cement containing goethite, hematite, and limonite.

### 3.1.2. Fine-Grained Ferruginous Sandstone (Local name: Gran Fina Marron): sample 2 - (ABNT-NBR-7389 – Microscopic analysis of petrographic polarized light test method))

This petrographic type consists of common and undulating grains of quartz, and the presence of gneiss fragments is very rare. The particle size ranges from medium to very fine sand, and the sample has very fine sand as the modal value with no gravel. The grains are moderately to well-rounded but also contain dominant angular grains with high sphericity, and the cement has a hematite and limonite composition. Fig. 4 shows a photomicrograph obtained from a polarized light microscope illustrating the interaction between the rock matrix and the rock cement. The ferruginous cement of this rock is much lighter and indicates a greater hydration of the cement binder of the quartz grains.

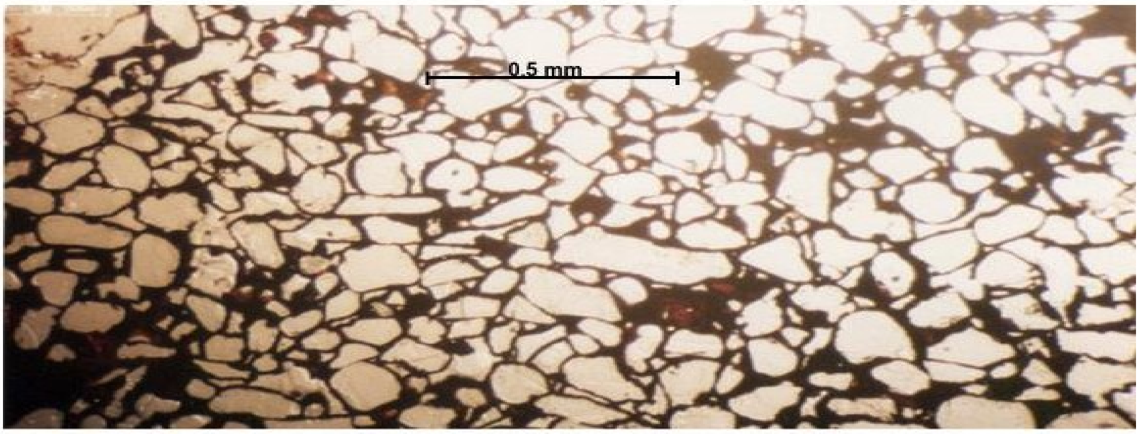

Figure 4. Photomicrograph of the fine-grained ferruginous sandstone and matrix/cement ratio. The sample presents a fine sand size as the modal value with subangular, high-sphericity grains and includes ferruginous hematite, goethite, and limonite cement.

### 3.1.3 Ferruginous conglomerate (Local name: Pedra Caroço – Cores Stone): sample 3 - (ABNT-NBR-7389 - Microscopic analysis of petrographic polarized light test method)

This type consists of granule grains as the modal value and grain size extremes ranging from very large to very small pebbles containing gravel and sand totaling less than 5%. This sample has a polycrystalline quartz matrix that is common and undulating with the rare presence of potassium feldspar. Rounding is subangular to subrounded with high sphericity. The cement has a hematite and limonite composition and varied color from grayish black to dark brown to light brown due to the oxidation and hydration of the laterized horizon. Fig. 5 shows a photomicrograph of the ferruginous conglomerate illustrating the matrix/cement ratio. The rock presents granule grains as the modal value, high sphericity, and a ferruginous cement of hematite, goethite, and limonite. The thick cementation exerts an influence on the rock's resistance.

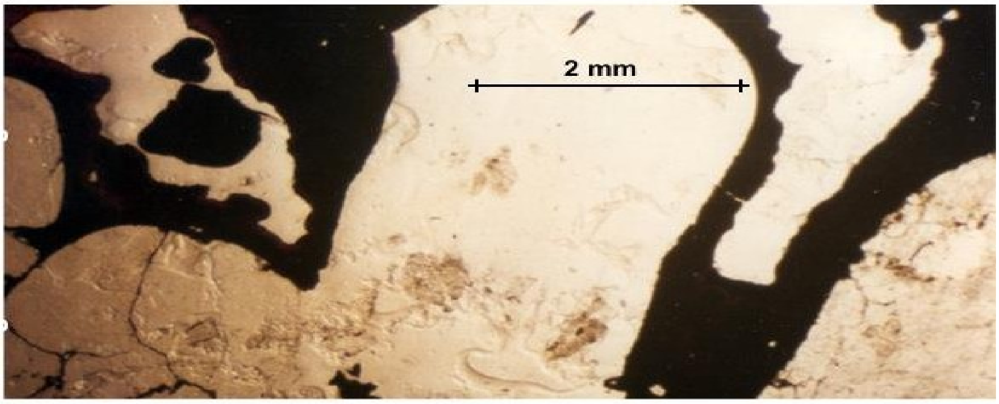


Figure 5 Photomicrograph of the ferruginous conglomerate illustrating the matrix/cement ratio. The rock presents granule grains as the modal value, high sphericity, and a ferruginous cement of hematite, goethite, and limonite. The thick cementation exerts an influence on the rock's resistance.

### 3.1.4 Clay–sandy sintered siltstone (Local name: Pedra jacaré – Alligator Stone): sample 4 - (ABNT-NBR-7389 - Microscopic analysis of petrographic polarized test method)

The texture of this petrographic type consists of very fine sand as the modal value and extremely fine sand and coarse silt. This sample is dominated by common quartz, and the rounding is subangular with low sphericity. The cement composition is hematite and limonite and has a grayish black color. Fig. 6 shows a photomicrograph obtained via a polarized light microscope illustrating the interaction between the rocky matrix and the rock cement.

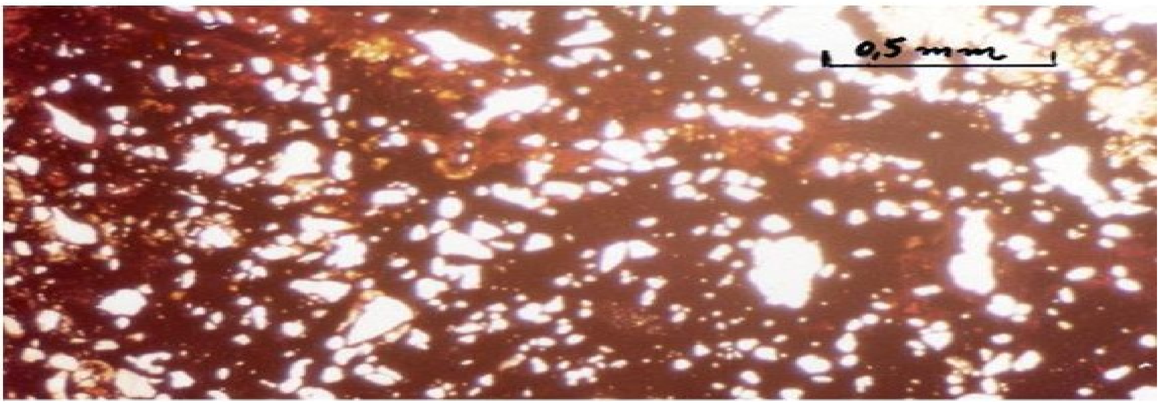

Figure 6 Photomicrograph of the clay–sandy siltstone concretion with fine sand as the modal value, subangular rounding and agglutination/cementation by the ferruginous minerals hematite, goethite and limonite, as well as kaolinite

### 3.1.5. Granulometric distribution

The result granulometric distribution is very important with respect to the Fuller curve theory, Fig. 7.

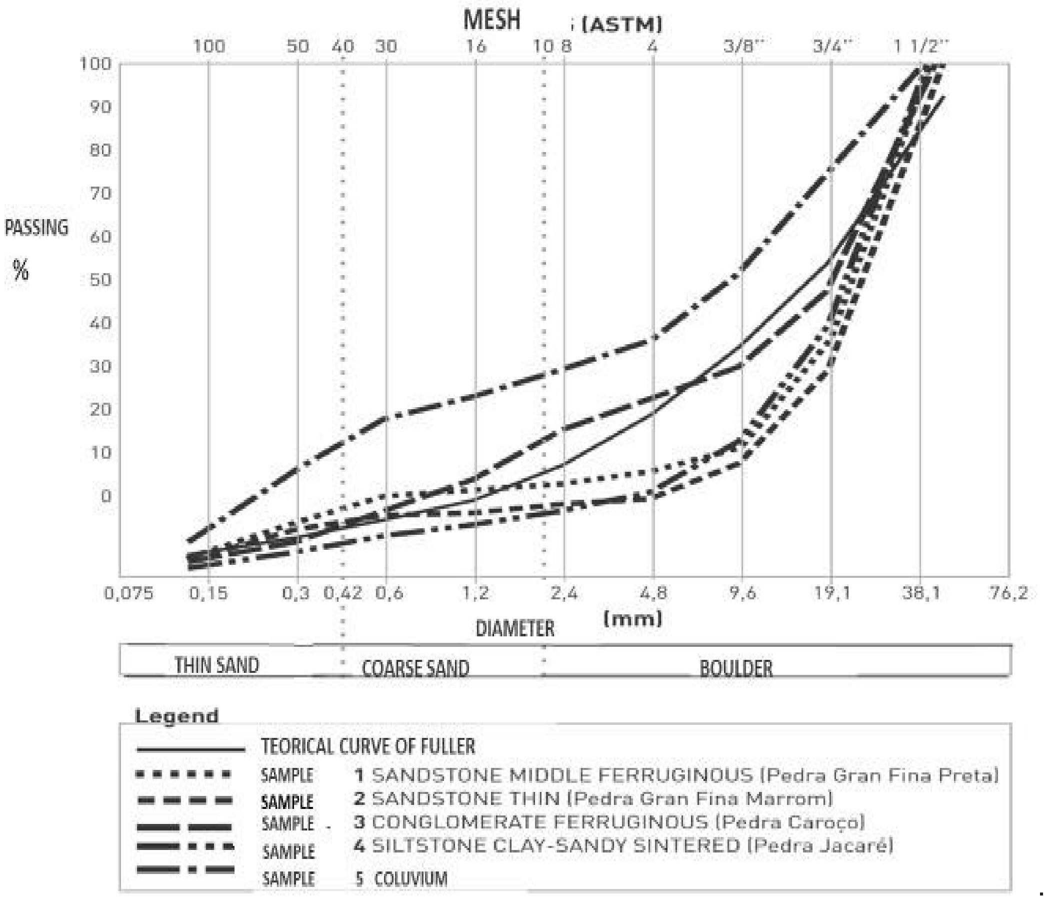


Figure 7 Granulometric curves of the petrographic types and Fuller curve theory

(ABNT-MB 7-specification).

### 3.1.6 Cement used in the molding of test pieces (ABNT-NBR-00 572 – Chemical analysis of Portland cement

To prepare the concrete specimens, we used 320 Portland cement manufactured in the city of Codó, Maranhão, Brazil, which was new and free from the effects of hydration. It is chemical properties are available on the factory website www.nassau.com.br.

## 4. CHEMICAL AND PHYSICAL CHARACTERISTICS OF THE LATERITE ROCK TYPES

### 4.1 Quantitative chemical and petrographic analyses of the rock types (DNER-ME-30-74 – Test Method)

The determination of the quantitative chemical components is based on Table 2. According to (DNER-ME- 30-74), the results of the quantitative chemical analysis are shown in Table 1. Special emphasis may be given to the iron oxide content found in all sample.

| ELEMENTS TYPES / OXIDES PERCENTAGENS | SANDSTONES THIN FERRUGINOUS (GRAN FINA MARROM) SAMPLE 2 | SANDSTONE MIDDLE FERRUGINOUS (GRAN FINA PRETA) SAMPLE 1 | SILTSTONE CLAY-SANDY SINTERED (PEDRA JACARÉ) SAMPLE 4 | CONGLOMERATE FERRUGINOUS (PEDRA CAROÇO) SAMPLE 3 |
|---|---|---|---|---|
| %$Al_2O_3$ | 3.2 | 4.7 | 16.1 | 2.6 |
| %$MnO_2$ | <0.05 | <0.05 | <0.05 | <0.05 |
| %$Fe_2O_3$ | 73.0 | 45.6 | 46.7 | 75.6 |
| %FeO | 0.17 | 0.18 | 0.09 | 0.08 |
| %$SiO_2$ | 16.0 | 43.1 | 23.9 | 8.8 |
| %CaO | 0.06 | 0.07 | <0.05 | <0.05 |
| %MgO | <0.05 | <0.05 | <0.05 | <0.05 |

**Table 1**. Oxide percentages of seven chemical elements (humid via) (DNER-ME-30-74 - Specification).

### 4.2 Summary of technological tests for the aggregates (IPT - M - 47, 49, 50, 52, 53, - Test Method) - (ABNT - MB - 170 - Test Method) - (DNER - DPT -M 89 - 44 - Test Method)

The determination of the specific mass dry apparent, specific mass saturated apparent, apparent porosity. water absorption, tenacity, crushing test, absorption test, simple axial compression rupture and sanity are in Table 2.

| Lithology of Petrografic Type | SANDSTONE MIDDLE FERRUGINOUS (GRAN FINA PRETA) SAMPLE 1 | SANDSTONES THIN FERRUGINOUS (GRAN FINA MARROM) SAMPLE 2 | CONGLOMERATE FERRUGINOUS (PEDRA CAROÇO) SAMPLE 3 | SILTSTONE CLAY-SANDY SINTERED (PEDRA JACARÉ) SAMPLE 4 | Methodology use |
|---|---|---|---|---|---|
| **TYPES OF TESTING** | **MEAN VALUES OF THE RESULTS** | | | | |
| Specific Mass Dry Apparent (g/cm$^3$) | 2.37 | 2.54 | 2.57 | 2.60 | IPT-M-47 |
| Specific Mass Dry Saturated Apparent (g/cm$^3$) | 2.55 | 2.61 | 2.67 | 2.70 | IPT-M-47 |
| Apparent Porosity (%) | 18.2 | 6.8 | 9.4 | 10.7 | IPT-M-47 |
| Water Absorptioin (%) | 7.7 | 2.7 | 3.6 | 4.1 | IPT-M-47 |
| Toughness – Tenacity (Treton impact) (%) | 66 | 52 | 64 | 28 | IPT-M-52 |
| Crushing Test (%) | * | 41 | 49 | 29 | IPT-M-53 |
| Abrasion Test Los Angeles (%) | 83 | 90 | 80 | 40 | ABNT-MB-170 |
| Simple Axial Compression rupture Tension - Mpa | 16 | 15 | 40 | 11 | IPT-M-50 |
| Shape of Fragments | Cubic | Cubic | Cubic | Cubic | IPT-M-49 |
| Sanity: Sieve Mosh (1”. 3/4” e 1;2”. 3.8”) (%) | * | 2.45 e 2.23 | 2.53. e7.4 | 34.35 e 36.86 | DNER-DPT-M-89-64 |

**Table 2.** Summary of technological tests for the aggregates (IPT-M-47, 49, 50, 52, 53 - Specifications) - (ABNT–MB–170 - Specification) - (DNER-DPT-M-89-64).

## 5 RESISTANCE TO SIMPLE COMPRESSION OF THE MOLDED PROOF FOR BODIES WITH DIFFERENT TRACES, 1:6 AND FACTOR A/C = 0.45 L/KG AND 0.50 L/KG OF CEMENT, TRACE 1:4 AND FACTOR A/C = 0.45 L/KG AND 0.50 L/KG OF CEMENT AND THE SLUMP TEST (ABNT–MB- 3 -37 – TEST METHOD) – (ABNT-MB-256 – TEST METHOD)

| Lithology of Petrografic Type | SANDSTONE MIDDLE FERRUGINOUS (GRAN FINA PRETA) SAMPLE 1 | SANDSTONES THIN FERRUGINOUS (GRAN FINA MARROM) SAMPLE 2 | CONGLOMERATE FERRUGINOUS (PEDRA CAROÇO) SAMPLE 3 | SILTSTONE CLAY-SANDY SINTERED (PEDRA JACARÉ) SAMPLE 4 | Methodology use |
|---|---|---|---|---|---|
| TYPES OF TESTING | MEAN VALUES OF THE RESULTS | | | | |
| Specific Mass Dry Apparent (g/cm$^3$) | 2.37 | 2.54 | 2.57 | 2.60 | IPT-M-47 |
| Specific Mass Dry Saturated Apparent (g/cm$^3$) | 2.55 | 2.61 | 2.67 | 2.70 | IPT-M-47 |
| Apparent Porosity (%) | 18.2 | 6.8 | 9.4 | 10.7 | IPT-M-47 |
| Water Absorptioin (%) | 7.7 | 2.7 | 3.6 | 4.1 | IPT-M-47 |
| Toughness – Tenacity (Treton impact) (%) | 66 | 52 | 64 | 28 | IPT-M-52 |
| Crushing Test (%) | * | 41 | 49 | 29 | IPT-M-53 |
| Abrasion Test Los Angeles (%) | 83 | 90 | 80 | 40 | ABNT-MB-170 |
| Simple Axial Compression rupture Tension - Mpa | 16 | 15 | 40 | 11 | IPT-M-50 |
| Shape of Fragments | Cubic | Cubic | Cubic | Cubic | IPT-M-49 |
| Sanity: Sieve Mosh (1”. 3/4” e 1;2”. 3.8”) (%) | * | 2.45 e 2.23 | 2.53. e7.4 | 34.35 e 36.86 | DNER-DPT-M-89-64 |

**Table 3.** Resistance to simple compression of the molded proof for bodies with different traces, 1:6 and factor A/C =0.45 l/kg and 0.50 l/kg of cement, trace 1:4 and factor A/C = 0.45 l/kg and 0.50 l/kg of cement and the slump test (ABNT–MB- 3 -37 – Test Method) – (ABNT-MB-256 – Test Method).

The resistance values to simple compression, the slump test, and the cement consumption for the different rock types are shown in Table 4. This higher resistance of ferruginous conglomerate has two causes: first, the ferruginous conglomerate, when crushed, provides a particle size (granulometry) that promotes the formation of concrete with a very dense matrix due to the internal arrangement and its concordance with the Fuller curve theory Fig. 7, and second, ferruginous conglomerate has a high tensile strength compared to that of other types due to its thicker ferruginous cement between grains, which results in greater cohesion.

Analyzing the results for the clay–sandy sintered siltstone shows that the disruptions are conditioned to the weaknesses of the planes that are not clumped together via laterization. This result explains the lower concrete strength for samples molded with this type of aggregate. It also appears that the medium-grained ferruginous sandstone has a higher resistance to breakage than the fine-grained ferruginous sandstone due to the cement being less hydrated and the grain contact surfaces being larger, providing greater internal friction. In addition, it is possible to conclude that, due to the granulometric curve of the medium-grained sandstone being more concordant with the Fuller curve theory shown in Fig. 7 and having a higher “Los Angeles” porosity/absorption/abrasion than the fine grained ferruginous sandstone, this type provides a granulometry closer to the Fuller curve theory and therefore offers a more compact concrete body with greater internal cohesion, i.e., a greater concrete resistance with a very dense matrix. The ferruginous conglomerate had a much higher resistance than the other samples for all traces and water/cement ratios at any disruption age.

## 6 CONCLUSION

The ferruginous conglomerate presented a value of 34,25 Mpa as the maximum resistance to simple compression when molded in Portland cement concrete, with a 1:6 trace and at a water/cement ratio of 0.45, Table 4. This petrographic type (ferruginous conglomerate), as an aggregate, presents better behavior for use in civil construction than the other petrographic types identified in this study, Fig. 7. The reason for this better behavior is that when the material is crushed, it provides a granulometric curve similar to that of the Fuller curve theory. In addition, the ferruginous conglomerate presents a thicker ferruginous cement with a greater contact surface between the grains and, therefore, a greater proportional resistance to the cohesive surface between the grains and the cement.

Of significant importance is the fact that the granulometric deficiencies presented by the other petrographic types, medium-grained ferruginous sandstone, fine-grained ferruginous sandstone, clay – sandy sintered siltstone and colluvial material, can be perfectly corrected with granulometric additions from other petrographic types to have a granulometry close to the Fuller curve theory, Fig. 7, resulting in a greater compressive strength for the molded concrete after such a correction.

The petrographic identification and technological characterization are both fundamentally necessary to using the stone material (lateritic aggregate) in a function concordant with its potential due to the variation in the results among each of the petrographic types.

The values of the simple compressive strength found in the tests carried out on samples from the surroundings of all petrographic types are in agreement with the values of the breaking resistance of the concrete specimens, except for the clay–sandy sintered siltstone, whose rupture is controlled by the fractions/portions not agglutinated via laterization.

The understanding of the stone material in São Luís, Maranhão, is very generic, and all the existing stone materials are identified as "black stone", which leads to an underutilization of these petrographic types according to the potential presented here for each individual type of lateritic aggregate.

If the lateritic aggregates in this region are not rationally exploited based on a mining practice that considers the identification demonstrated in this study, then these aggregates will be exploited predatorily, and these construction materials will be exhausted.

Finally, it was concluded that the São Luís aggregate has good technological characteristics based on the results obtained by the laboratory tests, especially considering that the use of laterite has been an alternative in regions devoid of crystalline stone material (e.g., granite). New world social paradigms have made governments give priority to stone materials in their infrastructure policies and, consequently, have made it necessary to discover new materials supported by technical and scientific knowledge that can participate in the production chain. In this aspect, the present study is of fundamental importance to Brazil and other countries worldwide.

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