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Geophysical Evaluation of Fine Aggregates Used in Concrete in The Municipalities of The Southern Region of Ceará

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ABSTRACT

The mesoregion Sul Cearense has followed the growth and urban expansion of Brazil and the state of Ceará and advances continuously with the increased demand for urban infrastructure works. This growth reflects in the increased use of natural materials such as fine aggregates due to the use of concrete as construction material. However, while the demand for sand increases, its availability and quality decrease proportionally, leading to the eventual use of sand of dubious quality. This situation motivated this work, whose main objective is to geophysically characterize the fine aggregates used in the southern mesoregion of the state of Ceará. To this end, the tests of specific mass, unit mass, swelling, particle size, clay clumps in friable materials, powder material and organic matter content were performed. The results obtained from the tests revealed that the studied sands are not suitable for use in reinforced concrete, because, besides not fitting the required granulometric ranges, they present high rates of powdery materials, clay clumps and friable materials in their composition.

INTRODUCTION

Urban growth and expansion bring with them great risks and dangers that are presented by the lack of adjustment and adherence of the production of urban space to natural systems. Brazil has been exponentially increasing its urban population over time, with this, much of the raw materials are being depleted (MARADONA JUNIOR *et al.*, 2013).

As a result of this great expansion, including in the construction industry, sand extraction is rampant, the adverse environmental impact must be analyzed and deepened, since in Brazil, other cultures and construction methods are little used. Thus, the high demand for fine aggregates, most commonly sand, and its scarcity in urban centers, leads to concern about the use of this material without its proper physical characteristics, which can lead to the production of concrete with low performance.

In the state of Ceará, the depletion of natural sand reserves is observed in some places. As a result, sand producers need to migrate in search of the product, in this perspective there is the possibility of using fine aggregates from Salgado River, which has great potential for sand deposit because it has approximately 308 kilometers of length, is born in '*Chapada do Araripe*' in Crato, with the name of Batateira River, has its watershed distributed by 25 cities, and in the municipality of Aurora, has the fulfillment of 42km (RIBEIRO, 2018). Despite the water pollution from effluents discharged by some municipalities, the Salgado River has high volumes of aggregates throughout its length, which can be characterized as an advantage for the construction industry (FONTENELE et al., 2011).

Aggregates are particulate materials, whose particles have varied dimensions, have no cohesiveness and chemical activity and help to increase the mechanical strength of concrete (SILVA E BARROS, 2018). The fine aggregates are grains of natural origin or resulting from crushing that pass through the 4.75 mm mesh sieve and are retained on the 0.15 mm mesh sieve (ABNT NBR 7211, 2005). Aggregates for the civil construction industry are the most consumed mineral inputs in the world. The demand in Brazil showed positive results of 3.5% between 2017 and 2018, with an estimated increase in subsequent years (MARQUES et al., 2020).

The aggregates used in the production of concrete are basically natural sands from river beds and artificial aggregates from rock crushing, in order to add volume and reduce the cost of concrete, besides contributing to its mechanical strength. According to Silva and Barros (2008), the sand used as aggregate must meet the requirements established by technical standards. Based on this, the physical study of the fine aggregates properties considers mainly: real specific mass, unit mass, water absorption, swelling, surface moisture, particle size, organic matter, clay clumps and powder material.

There are several techniques for extraction of fine aggregate from deposits, such as: manually, extraction in dry pits, in floodplain areas, in riverbeds and hydraulic blasting (SILVA, 2012). The incorrect sand extraction can irreversibly damage the environment, promoting adverse environmental impacts, such as increased water flow, bank erosion and destruction of riparian forests (MEIER, 2011). This environmental problem associated with the extraction of sand has challenged those involved in the construction sector to seek alternatives for the replacement of the material, among which are: Blast furnace slag; construction waste (CDW); gravel dust; discarded foundry sand (ADF) among others.

The search for knowledge about the physical quality of the fine aggregates used in the region of southern Ceará motivated this research. The main proposal is to develop the physical characterization and then verify the potential use of the sand extracted in this region for making concrete. Within this perspective, the minimum quality requirements according to the current laws will be pointed out.

MATERIALS AND METHODS

To conduct this research, it was necessary to divide it into two stages: The first through literature review, through journals, theses, monographs, dissertations and other scientific documents, and the second constant of the application of an experimental program, divided between the collection, preparation and characterization of samples.

Figure 1 below highlights the municipalities where the sand samples were collected. They are the municipalities Aurora and Lavras da Mangabeira, located in the south of the state of Ceará, on the eastern side of the ‘Chapada do Araripe’. The municipalities have an altitude of 283 m and are 430 km away from the capital Fortaleza (IBGE, 2022).

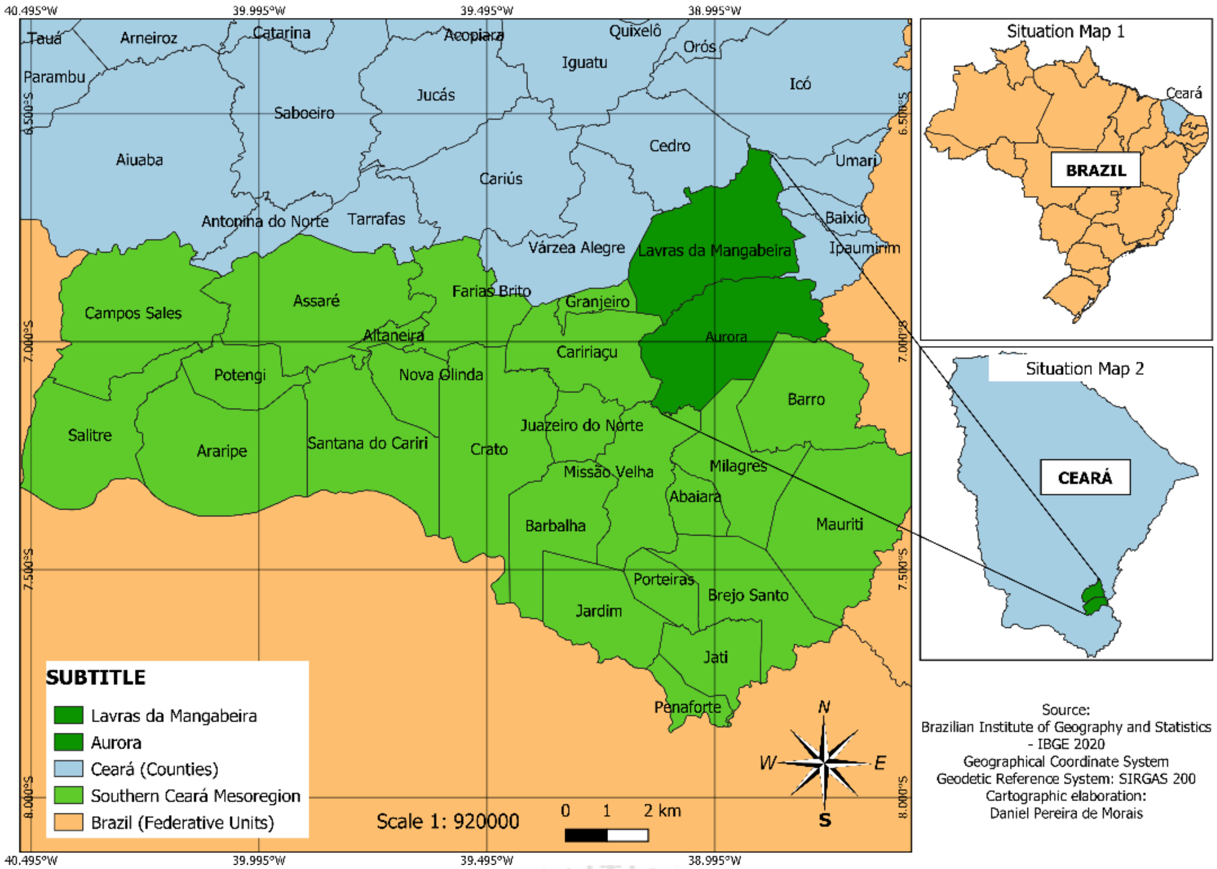

Figure 1 – Map of location of the municipalities studied

All procedures were guided by means of the Brazilian Standards – NBRs, and the methodological script for the preparation of the research was proposed as follows:

Sand collection

Three sand samples were studied, one from the Salgado River, another from the Oiticicas Creek, both in the municipality of Aurora, and the third one from the Rosário Creek in the municipality of Lavras da Mangabeira. The samples were provided by a construction material warehouse in the city of Aurora.

At first, according to the recommendation of NBR 6457 (ABNT, 2016) the sands were placed in the air to dry and taken to LAMESP (Soil Mechanics and Paving Laboratory), URCA, where the tests for their characterization were performed.

Particle size test

According to NBR 248:2003, this test is intended to present one of the main physical characteristics of sand, because the granulometry directly influences the quality of concrete and its workability. The tests were performed in duplicate, taking as a result the average obtained from the two tests.

Specific mass test

This test was performed to know the portion occupied by the aggregate particles, including also the interior pores of the particles. This property is of utmost importance for concrete dosage analysis, since it allows the calculation of the cement paste consumption, in its volume, according to the concrete mix.

Test of unit mass

For this test, followed the NBR NM 45: 2006 (Aggregates – Determination of unit mass and volume of voids) and was performed due to its importance for the transformation of the traces in weight to volume, and mutually.

Swelling test

Developed in accordance with the standard NBR 6467:2006 (Aggregates – Determination of swelling of fine aggregate – Test Method), with the interest of determining the increase in volume of the aggregate when wet, due to its direct influence on concrete quality.

Test of clods of clay and friable materials

Performed in accordance with NBR 7218:1987 (Aggregates – Determination of clay content in clods and friable materials) and was necessary as a result of the presence of clay clods in the sands, affect the workability of fresh concrete and consequently its final strength.

Test of organic matter content

The presence of organic matter in the sands was verified with the help of a muffle furnace. For this purpose, the organic matter content of the sand was taken as the average of the difference of the masses of three samples, before and after their submission to increasing temperature variation, until they reached 440ºC, for 12 hours, according to NBR 13600, ABNT (1996).

Test of powder content

The indication of the powder material content was performed according to the standard NBR NM 46:2003 (Aggregates - Determination of the fine material that passes through the 75 µm sieve). Its realization was due to the need of knowledge of the fraction of fines in the sands, since the presence in excess of powdery material in the fine aggregate increases the consumption of water to obtain the same consistency of the concrete, and may lead to the manifestation of pathologies in the construction, such as shrinkage and loss of strength.

RESULTS AND DISCUSSIONS

Specific mass

The results of the specific mass tests are presented in Figure 2.

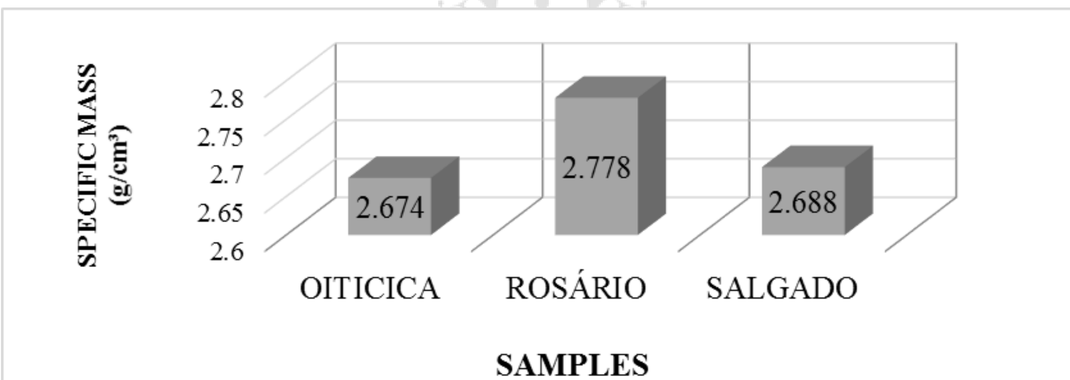

Figure 2 – Result of the specific mass tests of sands

As observed in Figure 2, the values of the specific masses of the samples were in the range of 2.67 to 2.78 g/cm^3 , fitting in the range between 2.60 and 2.90, which is, according to Das (2019), the relative density of the grains of some common minerals found in soils. On the contrary, low values of this density would indicate a small incidence of iron and/or aluminum in the material.

Unit mass

The results of the unit mass tests of the sands are presented in Figure 3.

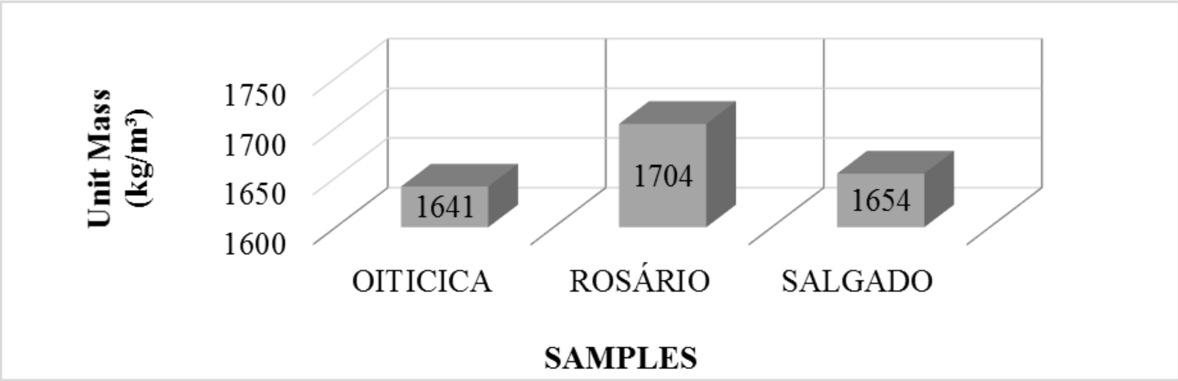

Figure 3 – Representation of the unit mass in the samples

As shown in Figure 3, the values of sand unit mass were between 1,500 kg/m³ and 1,800 kg/m³, which values are considered normal aggregates, and can be accepted for the production of conventional or normal concrete. On the other hand, aggregates with unit mass lower than 1,120 kg/m^3, would only be suitable for the production of light concrete, due to their highly porous cellular microtexture, while those with unit mass higher than 1,800 kg/m^3 would be suitable for the production of heavy concrete.

Swelling

The NBR 7211 (ABNT, 2005) does not establish a negation limit for the swelling of the sands, however, for Petrucci (1980), the average swelling of the soil should not exceed 6%. The results of the sand swelling tests are presented in Figures 4, 5 and 6.

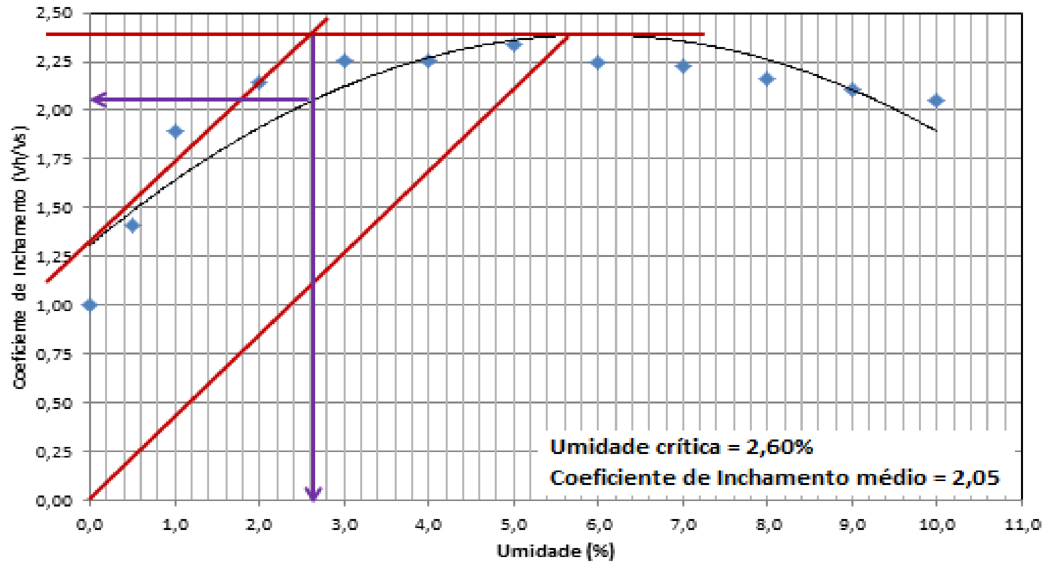

Figure 4 – Representation of the swelling in the Oiticica sample

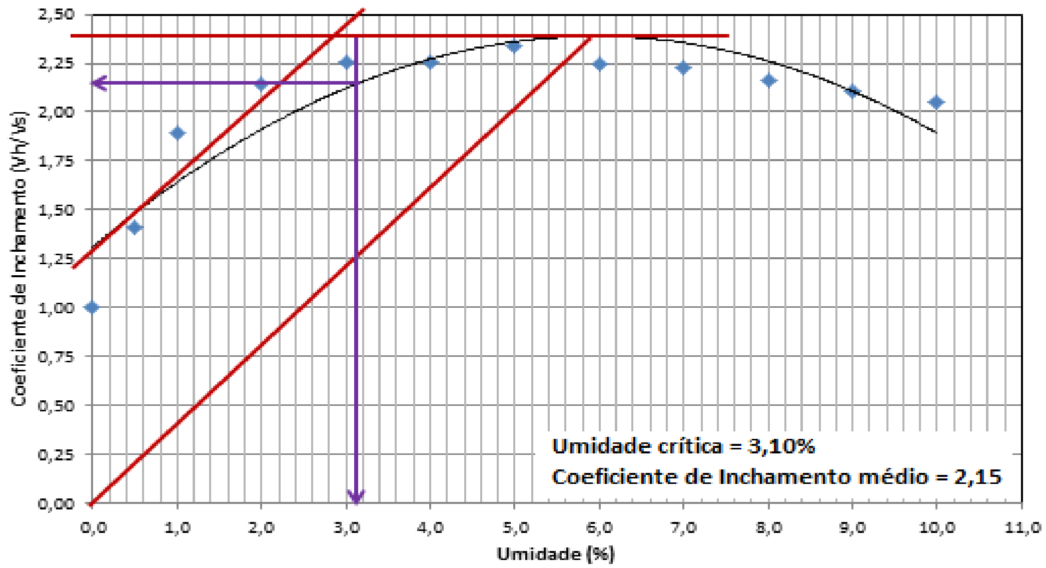

Figure 5 – Representation of the swelling in the Rosario sample

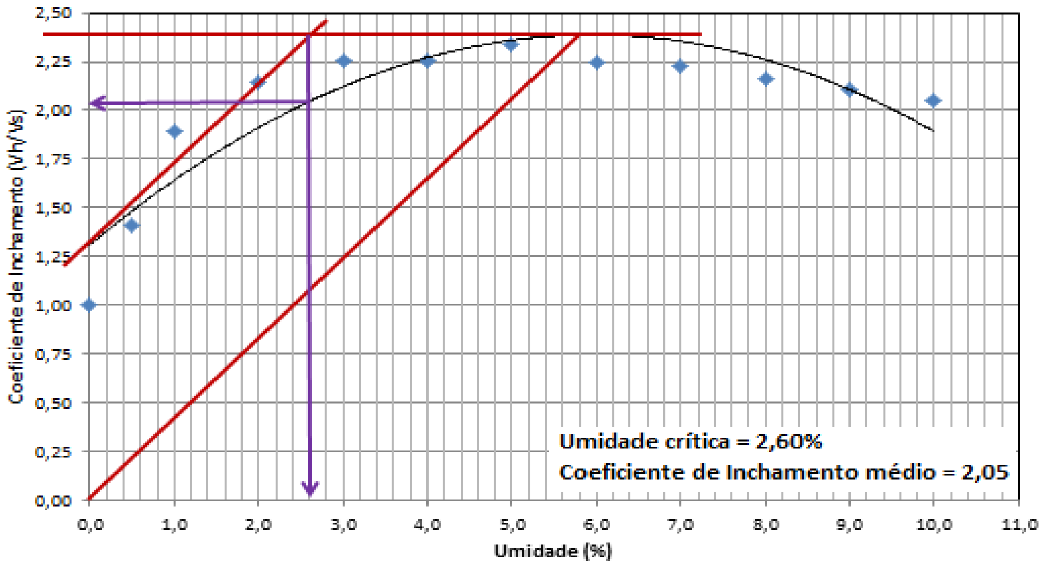

Figure 6 – Graph representing the swelling of the Salgado sample

As observed in figures 4, 5 and 6, the swelling coefficient was close to 2.0, with the lowest value in the Rosário sample, showing that this parameter depends on the granulometry and the aggregate moisture content, being higher for the finer sands, which have greater specific surface. It is noteworthy that the poor dimensioning of the sand swelling can create situations of risk for the concrete, since it modifies its volume, which can cause loss of concrete strength, due to the degree of swelling, besides modifying its dosage, requiring greater consumption of water and cement.

Granulometry

Table 1 presents the granulometric characteristics of the Salted sample.

Table 1 – Particle size characteristics of the Salted sample

AVERAGE GRAIN SIZE - SALTED						
# (mm)	Retained mass 1	Retained mass 2	Sample Average	% Retained	% Retained Accum.	% Pass
9,5	5,89	12,48	9,19	1,84	1,84	98,16
6,3	1,25	1,21	1,23	0,25	2,08	97,92
4,75	37,66	41,25	39,46	7,89	9,97	90,03
2,36	93,40	102,82	98,11	19,62	29,60	70,40
1,18	99,86	83,74	91,80	18,36	47,96	52,04
0,6	157,17	145,37	151,27	30,25	78,21	21,79
0,42	66,80	68,94	67,87	13,57	91,78	8,22
0,3	29,19	32,16	30,68	6,14	97,92	2,08
0,15	7,97	10,87	9,42	1,88	99,80	0,20
0,075	0,52	0,80	0,66	0,13	99,94	0,06
background	0,28	0,36	0,32	0,06	100,00	0,00
∑	500,00	500,00	500,00	100,00		
AM (g)	500,00	500,00	**FINENESS MODULUS**			**3,85**

Figure 7 represents in graph the particle size curve of the Salt River soil sample.

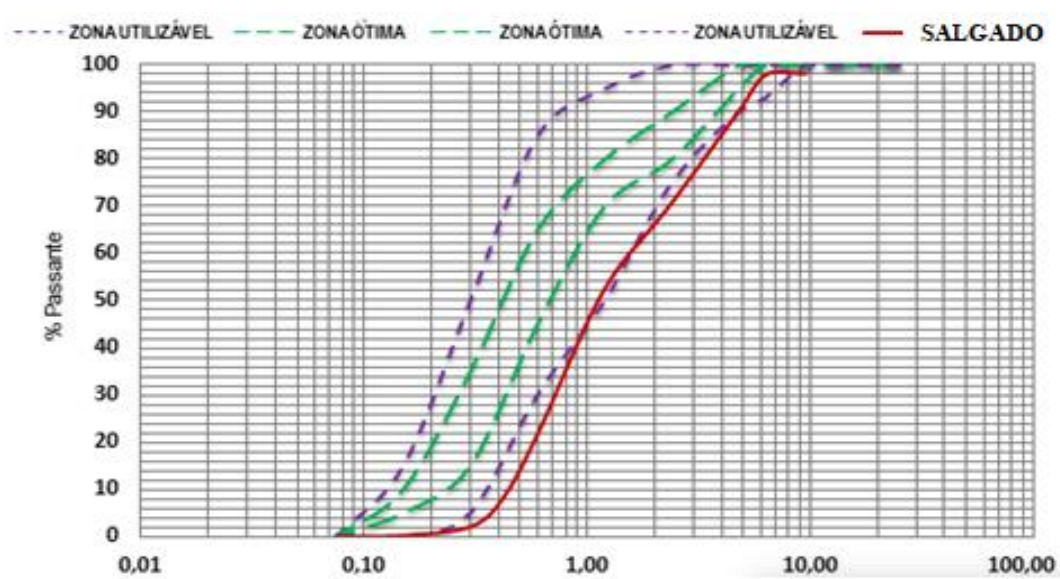

Figure 7 – Representation of the granulometry curve in the Salgado sample

Figure 7 shows that the Salgado sample (highlighted in red) is not within the usable zone, and is not characterized as fine aggregate, since the NBR 7211 (ABNT, 2005) recommends that these have grain sizes ranging from 4.75 to 0.015 mm. The maximum characteristic size of 19.0 mm helps to justify its poor granulometry.

Table 2 presents the granulometric characteristics of the Rosário sample.

Table 2 – Particle size characteristics of the Rosario sample

AVERAGE GRAIN SIZE - ROSARIO						
# (mm)	Retained mass AM 1	Retained mass AM 2	Average Samples	% Retained	% Retained Accum.	% Pass
9,5	0,00	0,00	0,00	0,00	0,00	100,00
6,3	0,00	0,00	0,00	0,00	0,00	100,00
4,75	2,47	3,51	2,99	0,60	0,60	99,40
2,36	21,82	21,87	21,84	4,37	4,97	95,03
1,18	26,99	29,92	28,45	5,69	10,66	89,34
0,6	80,66	86,13	83,39	16,68	27,34	72,66
0,42	81,15	83,46	82,31	16,46	43,80	56,20
0,3	113,97	117,84	115,91	23,18	66,98	33,02
0,15	100,22	90,67	95,44	19,09	86,07	13,93
0,075	45,05	42,30	43,67	8,73	94,80	5,20
background	27,70	24,30	26,00	5,20	100,00	0,00
∑	500,00	500,00	500,00	100,00		
AM (g)	500,00	500,00	**FINENESS MODULUS**			**2,00**

Figure 8 represents in graph the particle size curve of the Rosario sample.

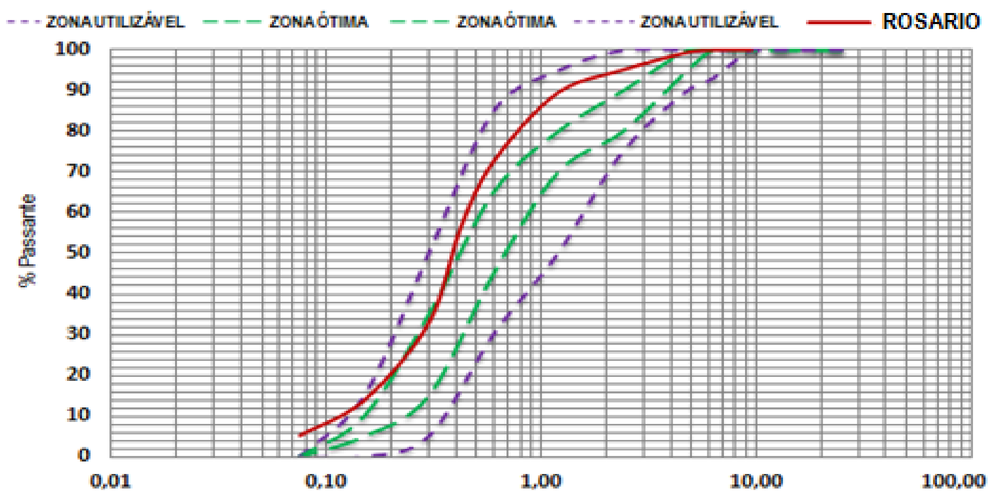

Figure 8 – Representation of the granulometric curve of the Rosario sample

In figure 8, can be seen that the curve of the Rosário sample is slightly close to the optimal zone, but it is outside the usable zone in its finest fractions. The maximum diameter of 2.36 and its fineness modulus of 1.93 characterize it as a "fine sand", making it unsuitable for concrete.

Table 3 shows the particle size characteristics of the Oiticica sample.

Table 3 – **Particle size characteristics of the Oiticica sample**.

AVERAGE GRAIN SIZE - OITICICA						
# (mm)	Retained mass AM 1	Retained mass AM 2	Average Samples	% Retained	% Retained Accum.	% Pass
9,5	7,17	7,17	7,17	1,43	1,43	98,57
6,3	2,05	2,05	2,05	0,41	1,84	98,16
4,75	16,35	16,35	16,35	3,27	5,11	94,89
2,36	42,16	42,16	42,16	8,43	13,55	86,45
1,18	51,92	51,92	51,92	10,38	23,93	76,07
0,6	140,22	140,22	140,22	28,04	51,97	48,03
0,42	108,52	108,52	108,52	21,70	73,68	26,32
0,3	85,40	85,40	85,40	17,08	90,76	9,24
0,15	39,60	39,60	39,60	7,92	98,68	1,32
0,075	5,44	5,44	5,44	1,09	99,77	0,23
background	1,17	1,17	1,17	0,23	100,00	0,00
∑	500,00	500,00	500,00	100,00		
AM (g)	500,00	500,00	**FINENESS MODULUS**			**2,84**

Figure 9 represents in graph the granulometry of the Oiticica sample.

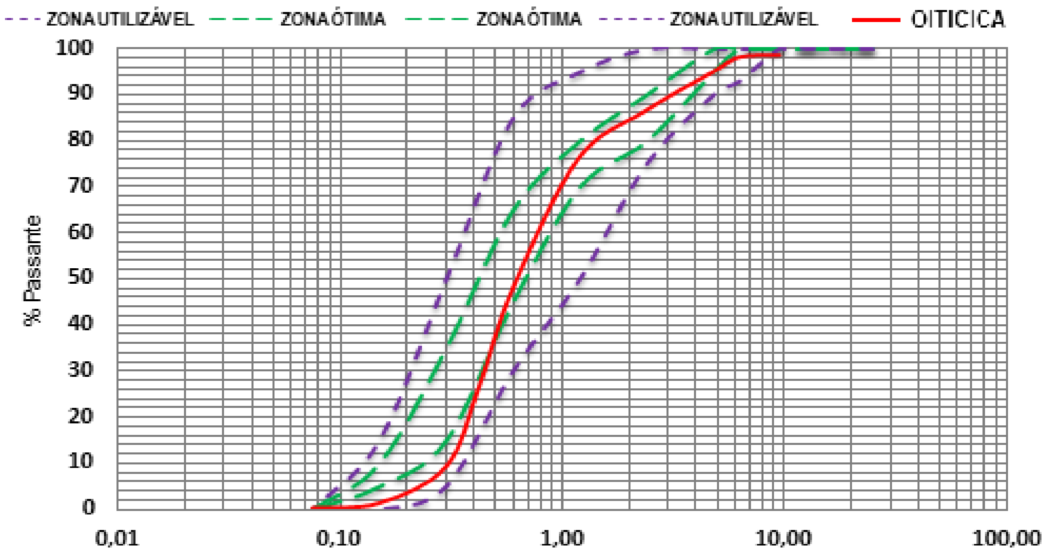

Figure 9 – Representation of the particle size curve of the Oiticica sample

As can be seen in figure 9, the particle size curve of the Oiticica sample is almost entirely between the upper and lower optimal zones, and can be considered a good fine aggregate in this regard.

Clays and friable materials

The results of the tests of clay clods and friable materials in the three samples are represented in graph in the figure 10.

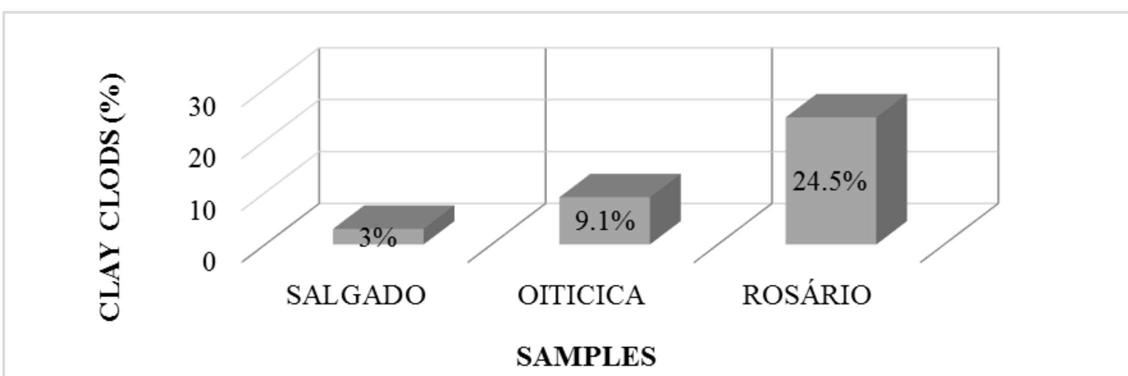

Figure 10 – Representation of the percentage of clay clods in the samples studied

As shown in figure 10, the samples Oiticica and Rosário had high rates of clay clumps and friable materials, 9.1 and 24.5% respectively. As the NBR 7211 establishes 3.0% as the tolerated limit of this undesirable material in fine aggregates, both samples become unsuitable for use in concrete. On the other hand, the Salgado sample, whose clay clod content was only 3.0%, would meet the standard, with respect to this question, but has its use disqualified for concrete due to its improper granulometry, as noted above.

In this context it is worth remembering that the high content of clay clumps in the fine aggregate can cause localized weak points in the concrete, reduce adhesion and cause losses in its strength.

Dusty materials

The results of the tests to determine the powdery material content in the samples are presented in figure 11.

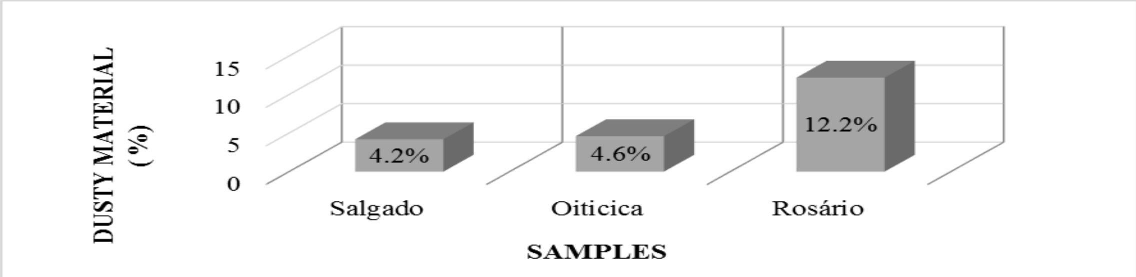

Figure 11 – Representation of the percentage of powdered material

As can be seen in figure 11, none of the samples meets the technical parameters established by the standard regarding the content of powdery material, since NBR 7211 (ABNT, 2005) tolerates only 3% of these in fine aggregates for concrete subjected to surface wear and 5% for concrete protected from surface wear.

Thus, it is concluded that the Salgado and Oiticica samples showed values not far from the tolerated limit, but the Rosário sample contains a high content of these undesirable materials, totally disqualifying it for concrete production. It is worth remembering that excess powdery material in the fine aggregate interferes with the cement hydration process, can form films that prevent or reduce the adhesion between the aggregate and the hydrated cement paste, damaging the strength and durability of concrete, in addition to increasing the surface area and, consequently, the water demand and cement consumption.

Organic matter content

Of the samples taken, 100% had low levels of organic matter. The results of the test are shown as graph in figure 12.

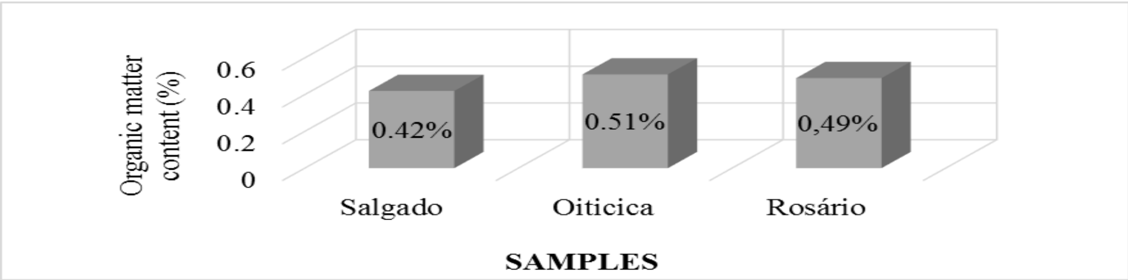

Figure 12 – Representation of the organic matter content in sand

It is noteworthy that aggregates in general contain organic matter, even if in small quantities; therefore, these indexes are within the expected normality, being suitable for use in civil construction according to standard 7211 (ABNT, 2005).

Table 4 presents the summary of the results of the tests performed to facilitate the understanding of the parameters studied.

Table 4 – Summary of the results studied

TESTS	SAMPLES		
	OITICICA	**ROSARY**	**SALGADO**
Specific mass (g/cm³)	2,674	2,778	2,688
Unit mass (kg/m³)	1.641	1.704	1.654
Powdery material (%)	4,60	12,20	4,20
Clay in clods (%)	9,10	24,50	3,00
Organic matter (%)	0,51	0,49	0,42
Granulometry	Usable Zone	**Not usable**	**Not usable**
Swelling coefficient (%)	1,17	1,16	1,21
Modulus of fineness	2,84	2,00	3,85
Sand type	Average	Fine	Very thick
FINAL ASSESSMENT	**IMPRESSIVE**	**IMPRESSIVE**	**IMPRESSIVE**

CONCLUSIONS

In general, the analyzed sands do not present technical conformity in all tests performed, none of them is recommended for use in concrete. The sample Oiticica, despite presenting a particle size curve within the usable zone, is not recommended for use in concrete due to the presence of 4.6% of powder material and 9.1% of clay clods and friable materials, besides containing 0.51% of organic matter in its composition.

The samples Rosário and Salgado besides presenting particle size curves outside the usable zone contain 0.49% and 0.42% organic matter, respectively. The Rosário sample showed 24.5% clay clods and friable materials, and also because it is very fine, it is economically unviable for use in concrete, because it requires a high consumption of cement and affects the cohesion of the mixture, with risks of segregation of the fresh concrete.

Finally, it is concluded that the analyzed samples are not suitable for concrete, although widely used in the southern mesoregion of the state of Ceará. The study showed the diversity of sands in the region and the need for local builders to be aware of their use in concrete, in order to avoid structural problems or other pathologies in buildings that may contribute to reducing the durability of buildings.

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