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Elaboration of Tables for Concrete Dosage Based on the Aggregates Used in Northeast Mineiro

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Abstract: Given the gradual increase in the technological level of the production of inputs, machines and other things directly and indirectly related to the civil construction industry, it is still necessary to carry out studies that study the characteristics of the materials of each region of the country and their applications to the concrete mixes traditionally used. Several studies show that variations in aggregates alter the final properties of the concrete produced, which makes it impossible to use general tables, as is customary in construction. In this perspective, the concrete dosage was studied using aggregates from the region of the Brazilian city of Teófilo Otoni, located in the northeast of Minas Gerais. Both in the use of regional aggregates, as well as in the application of binders currently used in Brazil and other aspects addressed in this work, the need for regionally applicable studies such as this one is evident, which brought results that triggered the creation of applicable, practical tables that represent an advance in the technology of concrete production in the region, and that can be applied on site, facilitating engineering projects and providing greater safety to users and executors of future projects.

Key words: dosage; concrete; trait; regional aggregates

1. Introduction

Civil construction methods in Brazil are characterized by being traditional, maintaining nostalgic methodologies and techniques. This nostalgia can be found in the concrete dosage practices, which in many projects significantly interfere with the final resistance of the structures.

Tables prepared in the 1960s usually become outdated and unviable due to the evolution of raw materials and because we are in a country with a large territorial extension like Brazil, where there is a great variability in climates, rock formations, reliefs and vegetation, which directly reflects on the available aggregates and the economic viability of their extraction method.

Therefore, based primarily on the mixture of these aggregates, cement and water, it is extremely important to study which characteristics of concrete can undergo variations. Such studies can bring better resource management to the civil construction industry, reduce costs and rework, ensure greater profitability and competitiveness for companies, in addition to guaranteeing users of projects greater safety due to greater prediction of the resistance achieved by the various mixes used in the projects.

Random factors related to the manufacture and preparation of concrete can interfere with the final resistance, such as the type of cement, the quality of the materials used, the curing time, the moisture available in the mixture during the curing process, the amount of air incorporated into the structure, the compaction performed, among other things. There are a range of essential factors to achieve quality concrete, but the first step to good concrete is the dosage of the base materials.

It can be seen and reported that in the history of concrete dosage in Brazilian civil construction, numerous studies have sought to standardize the mixes to be used in the day-to-day of the sector. However, the dependence on local aggregates and the constant evolution of binders alter the results obtained in each region of the country.

In this way, it is understood that there is a regional need, in which is the city of Teófilo Otoni, located in the interior of the State of Minas Gerais, Vale do Mucuri, to develop a study aiming at a greater knowledge of the final resistance to compression of mixtures used in local civil construction, with fine and coarse aggregates also used and extracted in the region itself, preparing dosage and mixture tables that can be used in projects in the civil construction sector.

1.1 Literature review

According to Albuquerque (2008, p.63), aggregate can be defined as a deagglomerated material, with low particle size and little chemical activity. It can receive other definitions such as: filer, crushed stone, running spout, crack, etc. These aggregates can also be classified according to the size of their particles, their origin and apparent specific weight.

Aggregates can be classified according to their origin, as follows: natural (Natural Aggregates) or industrial (Industrialized Aggregates). The first is found "in particulate form" in nature, while the second requires industrial deagglomeration processes to be obtained. (Albuquerque, 2008)

> (...) aggregates must be composed of hard, compact, stable, durable and clean mineral grains, and must not contain substances of a nature or quantity that may affect the hydration and hardening of the cement, the protection of the reinforcement against corrosion, the durability or, when required, the external visual appearance of the concrete. NBR7211 (ABNT, 2005, p.4).

Materials used in civil construction, such as sand, gravel and crushed stone are considered aggregates, but according to their granulometry they receive a more specific classification, for example: sand is considered fine aggregates and gravel and crushed stone are classified as coarse aggregates in the nomenclature adopted in civil construction.

According to Albuquerque (2008), sand is geologically an unconsolidated sediment and can have several origins, coming from rivers, quarries, crushing, slag, and beaches and dunes. Among all these possible types, the following types stand out in this work:

- River sand. (Washed sand). These include sediments deposited in the beds of certain rivers. They are extracted by dredging, which use suction to remove this material together with water, sending it to settling ponds, where the sand is separated. It is important to determine that the diameter of its grains does not exceed 4.8 mm, and is larger than 0.075 mm.
- Sand from crushing. This material comes from crushing in quarries and mining operations. After crushing, the sand is separated dry and then placed in moisture separators that remove material with diameters smaller than 0.075 mm, aiming for a higher quality product. However, "dry" or unwashed sand can also be used for concrete.

Sand grain size can be classified according to NBR 6502 (ABNT, 1995, p. 9) by the diameters of the rocks that compose it as: fine (0.06 to 0.2 mm), medium (0.2 to 0.6 mm) and coarse (0.6 to 2.0 mm).

Several rocks are suitable for use in the production of aggregates in the industry, and in each region the costs for production or availability of a type of rock become more viable. This economic viability that directs the production of aggregates for civil construction increases the variability in concrete produced throughout the country. The search for competitiveness brings to the market an excessive need for cost reduction.

For aggregates, the rocks commonly mined are granite, basalt, gneiss, limestone, sandstone, blast furnace slag, hematite, among others. Each of these rocks has varying values of density, mechanical resistance to different types of acting forces (compression, bending and traction), Poisson's ratio, and modulus of elasticity.

The production of Portland Cement itself could also undergo variations. However, these are negligible due to the existence of regulations that guide the entire production, ensuring the effective standardization of the binder to be marketed, which does not happen in the dosage of concrete, which has no regulatory standards. Therefore, the variations in concrete are related to the aggregates.

ABNT, through NBR7211 (ABNT, 2005, p.5) provides guidelines for the receipt and production of aggregates, both fine and coarse, that will be used in the production of concrete, but does not guarantee efficient dosages of these materials.

According to the Brazilian Association of Technical Standards, NBR 5732 (ABNT, 1991, p. 8), Common Portland Cement is a "hydraulic binder obtained by grinding Portland clinker to which the necessary quantity of one or more forms of calcium sulfate is added during the operation." According to this standard, pozzolanic materials, granulated blast furnace slag and/or carbonate materials can be added during grinding, in the amounts specified therein. Thus, at the end of the process, it becomes a binder that reacts with water and hardens, bringing with it a range of important characteristics and resistances, such as compression.

The materials mentioned above are commonly used to produce conventional concrete, such as fine and coarse aggregates and Portland cement, with the addition of water, which reacts with the binder and allows the mixture to solidify. The mixture of each material in the appropriate proportion results in the final product called the 'mixture' or concrete dosage, which in this study followed the following order: Cement: Fine Aggregate (Sand): Coarse Aggregate (Gravel). However, according to Pimenta (2009), there may be several types of aggregates or cementitious materials on site. The author points out the importance of field and laboratory studies to characterize the various materials available for a project. Such studies, which may involve dosage and testing of concrete, may indicate the materials that meet the quality requirements and the cost they generate for the building.

Studies conducted by Ribeiro et al. (2016), reported, through a probabilistic cluster sampling, the conditions for the dosage of concrete for general construction projects produced in the city of Angicos/RN. The authors' work aimed to analyze the production of concrete without any technical concern regarding the final properties achieved, such as static modulus of elasticity, dynamic modulus of elasticity and compressive strength. It is concerning that this represents the majority of what is happening in Brazil, as the study shows that in more than half of the projects where data is collected, the compressive strength of concrete is below 20 MPa, which sets the minimum value for structural concrete according to NBR 6118 (ABNT, 2014). The fact that some of the projects evaluated, which did not meet the requirements of the standards for structural concrete, were public buildings under federal management, mitigated the concern about the lack of supervision and criteria on the part of the government itself in relation to the subject in the country.

As reported by Tutikian and Helene (2011), Brazil does not have regulations that standardize concrete dosage, which leads many scholars in the area to propose their own and particular dosage methods. Dosage studies have been carried out with the aim of optimizing the best and most economically accessible mixture in a given region, using local materials. This makes it possible to achieve a series of requirements, such as mechanical resistance, which is generally the most analyzed parameter. "There are mixtures with excess or insufficient sand, gravel and/or water, characterizing the absence of effective dosage methods." (Ribeiro, et al., 2016, p. 731)

The principles of dosage of concrete constituents can be presented in a fundamental manner, as in the studies reported by Tutikian and Helene (2011), the first being the precursor to the compressive strength of concrete, which is the water/cement ratio. The consistency of the concrete can be related to the amount of water per m³ applied, which makes this a parameter to be accounted for in this study.

NBR7211 (ABNT, 2005) indicates that if there is a lack of antecedents related to the performance of aggregates in certain areas where it becomes economically unfeasible to obtain aggregates provided for by the standard with all its requirements, their use for the production of concrete must be preceded by studies and experiments carried out with quality and documented by duly qualified professionals. In contrast, the panorama observed by Ribeiro et al. (2016, p. 732) shows that "concrete is widely used as a construction material, with little or no monitoring", which increases the relevance of studies in this area.

According to Thomas E. C. S (2000), Civil Engineer Caldas Branco was the first to produce concrete mixes by relating their dosage in weight or volume in Brazil, through a series of numerous experiments and laboratory tests. The study used cylindrical test specimens measuring 15 cm × 30 cm, as is still required by Brazilian regulations today. At the time, the binder used was Common Portland Cement, known as CPI, based on a mixture of plaster and clinker, which was manufactured in Rio de Janeiro with crushed gneiss rocks and Mauá quartz sand. In the past, mixes were determined in less rigorous ways and were generally not even tested, especially in small-scale projects, which led to great variability in resistance and projects prone to errors. Aiming for the desired resistance, Caldas Branco developed several mixes in the 1960s, which were applied in the city of Rio de Janeiro and gradually spread throughout the country. Given the importance of the work carried out by Civil Engineer Caldas Branco, who carried out several studies that had never been published before in the area, he was awarded the Ary Frederico Torres Award "Highlight of the Year in Concrete Technology" by the Brazilian Concrete Institute - IBRACON in 1984, which was a great recognition of his work. In his research, he developed manuals, guidelines and standards, with 12 mixes that were later organized into a table, which is still widely used in the construction industry due to its practicality in producing concrete according to the desired compressive strength results.

However, this table, popularly known as the Caldas Branco Table, was already incompatible with being applied in all locations in Brazil, given the regional particularities it had, since it was prepared based on aggregates from the city of Rio de Janeiro. Thus, in other cities it did not produce the same results due to the use of other types of aggregates and other variability in production.

Barbosa and Bastos (2008) point out that the concrete mixes shown in older tables are still widely used in the production of concrete in smaller projects, and that they do not meet the quality requirements of current regulations.

Tutikian and Helene (2011) mention some dosage methods, each with its own peculiarities, benefits, and also difficulties in application, whether due to the need for specific software or because they involve complex analyses. These, considered current, were developed by researchers from several countries, as shown below:

The ACI (American Concrete Institute) has four dosing methods:

- Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete;
- ACI 211.2-98 (Reapproved, 2004) - Standard Practice for Selecting Proportions for Structural Lightweight Concrete;
- ACI 211.3R-02 (Reapproved, 2009) - Guide for Selecting Proportions for No-Slump Concrete;
- ACI 211.4R-08. Guide for Selecting Proportions for High Strength Concrete Using Portland Cement and Other Cementitious Materials.

There is also the De Larrard Method, a French researcher, the Vitervo O'Reilly Method, a Cuban method, and the IBRACON (Brazilian Concrete Institute) method. However, there are studies carried out in Europe on the dosage of concrete and mortar around the beginning of the 19th century. (Tutikiane; Helene, 2011)

Today, not only are there different types of concrete aggregates, but the Portland cement produced has also evolved, with much higher quality standards and strict regulations that were almost non-existent at the time. All this evolution in binders also changes the proportions needed to obtain the same resistance considered in comparison with the Caldas Branco table, or others from the past.

The city of Teófilo Otoni is located in the northeast region of the State of Minas Gerais, with an estimated population of 140,567 thousand inhabitants, according to the Brazilian Institute of Geography and Statistics - IBGE (2014). Among its economic activities, we can highlight the large number of engineering and civil construction projects. As it stands out as a hub city, not only economically, but also in the mineral extraction sector, it is able to produce its own inputs and aggregates for its own use and also meet the demand of neighboring cities such as Novo Oriente de Minas, Poté, Ladainha, Águas Formosas, Carlos Chagas, among others.

The aggregates used in the region are extracted by local quarries and are of two types: crushed and natural. As already presented in previous paragraphs, their types can also cause variations in the final strength of the concrete produced.

Based on the questions and information obtained, it is possible to reflect the need for regional research and the production of new tables that meet the local realities of the city of Teófilo Otoni and the region in the production of concrete. In this context, the study aimed to obtain two tables for concrete dosage, presenting the mixtures obtained and their resistances tested as prescribed in Brazilian regulations for concrete produced with "medium washed sand" and "medium artificial sand", both sold in the region.

2. Methodology

2.1 Materials

The materials listed below were used in the analysis procedures, specimen production, specimen rupture and other tests presented in this paper.

- Cement CPIII-40-RS InterCement;
- Artificial sand (gneiss) and medium washed sand;
- Gravel (artificial - gneiss);
- Concrete mixer CSM-145L;
- 30 cm tall truncated cone-shaped metal mold, 10 cm in upper diameter and 20 cm in lower diameter;
- 50 × 50 cm² metal plate with base;
- Metal tamping rod with hemispherical end of 1.6 cm diameter;
- 30 cm graduated ruler;
- Scale;
- 15 × 30 cm cylindrical metal molds for specimen production;
- SOLOCAP digital electric hydraulic press – Model 4HCIC, 100 tons, inspected;
- Molds for test specimens;

2.2 Tests

The Brazilian Association of Technical Standards (ABNT) regulates not only the materials, but also the technical procedures for testing these materials and test specimens.

In this work, four tests were performed, the first of which was on the moisture content of fine aggregates, with the aim of better characterizing the materials used in the tests, which provides the reader with maximum information and also establishes parameters for discussing possible results that would be obtained later in the following tests. For this purpose, following NBR7217 (ABNT, 1987), the granulometry of the sands to be used, both natural and artificial, was tested.

The relative moisture content of the fine aggregates was calculated as a percentage using the following Equation 1 illustrated below, for both natural and artificial sand:

$$\text{Moisture} = \frac{\text{Wet Weight - Dry Weight}}{\text{Dry Weight}} \times 100 \quad \text{Equation 1 – relative humidity}$$

The second test, called the slump test, described and detailed by NBR NM 67 (ABNT, 1998), was carried out with the aim of obtaining a defined standard for the workability and consistency of the concrete produced to be placed in the test specimens. In this way, an average value for the slump was standardized, around 8 +/- 2 cm, that is, concretes that were produced and that did not present values between 6 and 10 cm were discarded and new mixes and quantities of water were determined.

Figure 1. Slump test. (Source: Author's personal archive)

Below, in Figure 2, we have a mixture that did not meet this specification and obtained a slump of around 20 cm:

Figure 2. Concrete with slump of around 20 cm.
(Source: Author's personal archive)

Concrete curing is a very important process, because according to Bauer (2001, p. 260) "curing in water significantly reduces the shrinkage of the piece in the phase in which the concrete has low resistance, preventing the formation of cracks resulting from shrinkage, which can compromise the impermeability of the concrete".

Another phenomenon related to concrete curing is that the low hydration of the concrete allows the temperature to increase, since this is an exothermic reaction, which tends to expel water from inside the mixture to the external environment. This fluid exit leaves paths that reduce the final resistance of the concrete, which cracks more easily.

In the work entitled "Influence of the Curing Process in Conventional Concrete", according to Silva et. al. (2012), in six stages, the CP IV - 32 RS RRAA pozzolanic cement was used in the production of concrete. It is resistant to sulfate attacks and the alkali-aggregate reaction. Its specific mass is 2940.00 kg/m³ and its strength to be achieved after 28 days was 32 MPa. In this study, the strength of the concrete was compared with curing in the open air, together with curing by immersion, and it was possible to observe considerable gains in strength in test specimens submerged in water.

According to NBR 5738 (ABNT, 2003), the procedures for moulding and curing test specimens and two types of curing for them, wet curing and submerged curing, are described. However, on site, given a series of factors, it is difficult for either of these types of curing to occur. It is well known that no structure, when it is being cast and concreted in civil engineering works on the surface, remains immersed in water or is subjected to rigorous moisture treatment to such an extent that, if the standard is met, there is a discrepancy between the final resistance values obtained in the test specimens and the actual resistances obtained on the construction sites.

Therefore, due to the experimental nature of this work, and to approximate the reality of reinforced concrete structures that exist today in the region, the test specimens prepared in this work were not hydrated as prescribed in the standard.

After such discussions, it was decided to cure in the open air, in which the test specimens were wetted at intervals possible to perform on site (every half hour), during business hours (from 7 am to 5 pm, including weekends). This is also the period of greatest incidence of sunlight, and therefore crucial to prevent the evaporation of water from the test specimens, a process that compromises the hydration of the cement and increases the void index in the concrete, reducing its resistance. This gives this work a practical perspective that is more faithful to the day-to-day operations of the projects.

During the concrete curing regime, the water that makes up the concrete capillaries will be replaced by hydration products, a process that is increasingly effective in an environment close to saturation (Berhane, 1984).

The compression test followed the guidelines set forth in NBR 5739 (ABNT, 2007) and was performed on test specimens after curing in the open air. For each mix, 4 test specimens were prepared, one of which was broken on the seventh day, another on the fourteenth day, and the remaining ones on the twenty-eighth day.

The tests were also performed on two types of sand typical of the region: washed medium sand (river sand) and crushed sand, both using artificial coarse aggregate. Each finished test specimen was identified with the line, slump, time of manufacture, date, and name of the molder, to facilitate recognition and increase quality control of the experiments, as shown in figures 3 and 4 below.

Figure 3. Newly manufactured test specimens.

Figure 4. Identification on the test specimen.

Source: Author's personal archive

After the rupture of the cement, the results were sequentially displayed in tables to facilitate visualization and subsequent use in construction work in the region.

The Water/Cement (W/C) factor was also calculated, an important parameter for evaluating the proportions of binder and water used in the mixture and which is directly linked to the final strength of the concrete, since the greater the quantities of binder with cementitious properties, the greater the final strength observed tends to be.

Finally, it is important to emphasize that the container used as a dispenser was the same for the cement, gravel and sand, and its mass was measured before use. The method used to determine the quantity of material applied in each mix was to subtract the value given by the scale for the container full of cement from the value found for the empty container.

3. Results and Discussions

This section will present the results obtained and the questions necessary to prepare a table that includes the aggregates used in civil construction in the study region, the city of Teófilo Otoni - MG and other neighboring cities.

The following table is obtained from the humidity test:

Table 1. Relative humidity of aggregates

Aggregate	Wet weight - Ph	Dry weight - Ps	Humidity (%)
Natural sand	200.00	189.50	5.54
Artificial sand	200.00	181.50	10.19

Source: Author's personal archive.

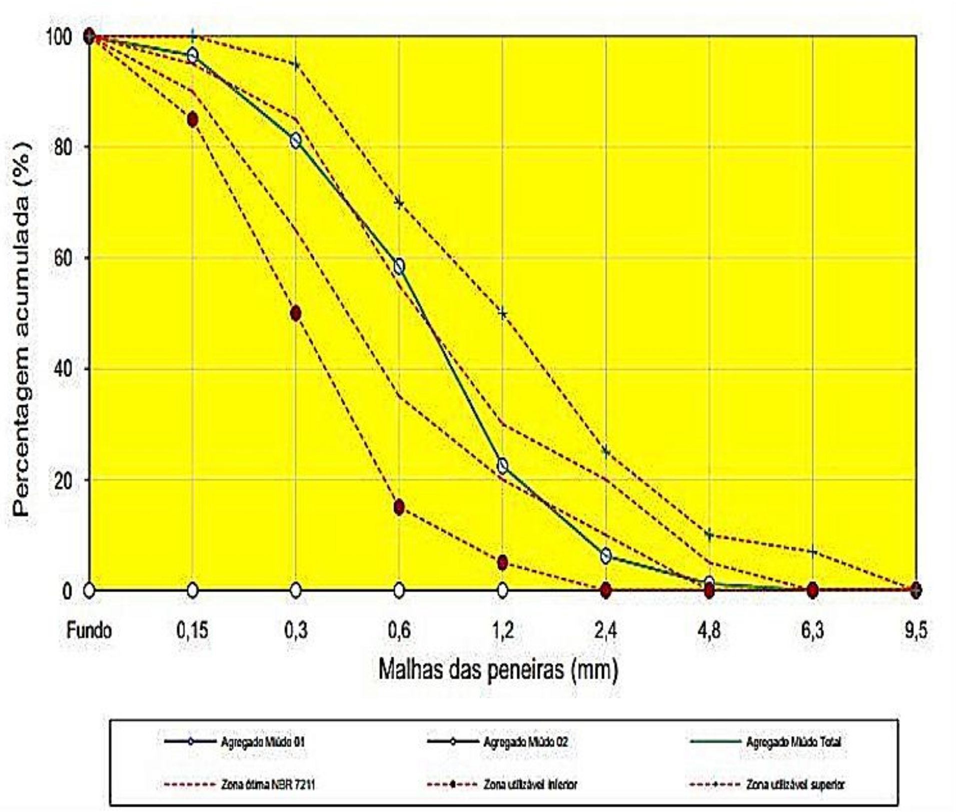
From the granulometric composition test of fine aggregates, we have tables 2 and 3 and graphs 1 and 2 below according to NBR7217 (ABNT, 1987):

Table 2. Fine aggregate - washed medium sand (Source: Author's personal archive)

Granulometric composition of materials				
Test date 05/13/2015	% Total small aggregate		Initial mass	Final mass
	Small aggregate 01	100%	1000.00	999.00
	Small aggregate 02	0%		0.00

Sieves (mm)	Small aggregate 01			Small aggregate 02			Total small aggregate	
	mass	% Retained	% Accum	mass	% Retained	% Accum	% Retained	% Accum
9.5	0	0.0	0	0	0	0	0.0	0
6.3	0	0.0	0	0	0	0	0.0	0
4.8	12.0	1.2	1	0	0	0	1.2	1
2.4	50.0	5.0	6	0	0	0	5.0	6
1.2	162.0	16.2	22	0	0	0	16.2	22
0.6	360.0	36.0	58	0	0	0	36.0	58
0.3	227.0	22.7	81	0	0	0	22.7	81
0.15	153.0	15.3	96	0	0	0	15.3	96
Bottom	35.0	3.5	100	0	0	0	3.5	100
Dim. Max.	4.8 mm						4.8 mm	
Fineness	2.66			0			2.66	

Graph 1. Granulometric curve of materials - medium washed sand. (Source: Author's personal archive)



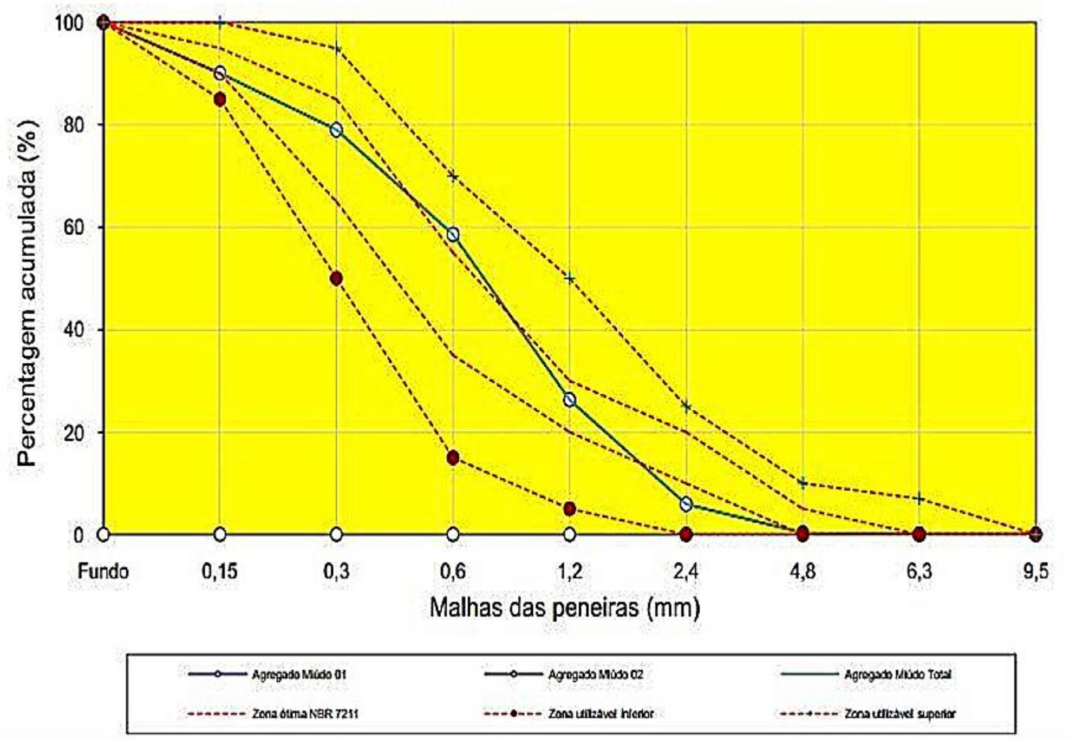
Notes: 1. The fineness modulus of the optimum zone ranges from 2.20 to 2.90; 2. The fineness modulus of the lower usable zone ranges from 1.55 to 2.20; 3. The fineness modulus of the upper usable zone ranges from 2.90 to 3.50

Table 3. Fine aggregate - artificial sand

<table>
<tr><th colspan="9">Granulometric composition of materials</th></tr>
<tr><td colspan="2" rowspan="3">Test date
13/05/2015</td><td colspan="3">% Total small aggregate</td><td>Initial mass</td><td>Final mass</td><td colspan="2" rowspan="3"></td></tr>
<tr><td colspan="2">Small aggregate 01</td><td>100%</td><td>1000.00</td><td>1000.00</td></tr>
<tr><td colspan="2">Small aggregate 02</td><td>0%</td><td></td><td>0.00</td></tr>
<tr><td rowspan="2">Sieves (mm)</td><td colspan="3">Small aggregate 01</td><td colspan="3">Small aggregate 02</td><td colspan="2">Total small aggregate</td></tr>
<tr><td>mass</td><td>% Retained</td><td>% Accum</td><td>mass</td><td>% Retained</td><td>% Accum</td><td>% Retained</td><td>% Accum</td></tr>
<tr><td>9.5</td><td>0.0</td><td>0.0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0.0</td><td>0</td></tr>
<tr><td>6.3</td><td>0.0</td><td>0.0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0.0</td><td>0</td></tr>
<tr><td>4.8</td><td>3.0</td><td>0.3</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0.3</td><td>0</td></tr>
<tr><td>2.4</td><td>56.0</td><td>5.6</td><td>6</td><td>0</td><td>0</td><td>0</td><td>5.6</td><td>6</td></tr>
<tr><td>1.2</td><td>204.0</td><td>20.4</td><td>26</td><td>0</td><td>0</td><td>0</td><td>20.4</td><td>26</td></tr>
<tr><td>0.6</td><td>323.0</td><td>32.3</td><td>59</td><td>0</td><td>0</td><td>0</td><td>32.3</td><td>59</td></tr>
<tr><td>0.3</td><td>204.0</td><td>20.4</td><td>79</td><td>0</td><td>0</td><td>0</td><td>20.4</td><td>79</td></tr>
<tr><td>0.15</td><td>111.0</td><td>11.1</td><td>90</td><td>0</td><td>0</td><td>0</td><td>11.1</td><td>90</td></tr>
<tr><td>Bottom</td><td>99.0</td><td>9.9</td><td>100</td><td>0</td><td>0</td><td>0</td><td>9.9</td><td>100</td></tr>
<tr><td colspan="2" rowspan="2">Max. Dim.
Fineness</td><td colspan="2">4.8 mm</td><td colspan="3"></td><td colspan="2">4.8 mm</td></tr>
<tr><td colspan="2">2.60</td><td colspan="3">0</td><td colspan="2">2.60</td></tr>
</table>

Source: Author's personal archive.

Graph 2. Granulometric curve of materials - artificial san. (Source: Author's personal archive)



Notes: 1. The fineness modulus of the optimum zone ranges from 2.20 to 2.90; 2. The fineness modulus of the lower usable zone ranges from 1.55 to 2.20; 3. The fineness modulus of the upper usable zone ranges from 2.90 to 3.50

The final results of all tests were presented in two tables with the following columns: Series, Mix, Date, Time, Water Volume in L, A/C Factor, Slump (cm) and Compressive Strength at 7, 14 and 28 days. In summary, two other tables were prepared, with the average strengths already calculated, which presented the results in a concise manner, thus obtaining Tables 4 and 5, presented below:

Table 4. Average artificial sand

Concrete strength table - Medium artificial sand 09/05/15							
Series	Feature	Vol. Water (l)	A/C factor	Slump (cm)	Average strength (MPa)		
					7 days	14 days	28 days
1	01:01:02	1.8	0.46	6.5	13.41	15.47	18.52
2	1: 1 1/2:2	1.55	0.39	6.5	21.73	24.92	33.08
3	01:02:02	1.5	0.38	8	20.32	26.17	32.70
4	1:2:21/2	1.75	0.45	6	13.48	19.14	25.85
5	01:02:03	2.21	0.56	6.5	11.11	16.67	19.60
6	1:2 1/2:3	2.4	0.61	8.5	10.56	12.30	17.80
7	01:03:03	2.3	0.59	9.5	10.04	13.55	16.65
8	01:03:04	2.3	0.59	8.5	6.79	9.36	13.40
9	01:04:04	3	0.76	6	7.53	10.94	13.00
10	01:04:05	3.2	0.82	6	4.93	7.15	9.30
11	01:05:05	3.5	0.89	6,5	3.43	4.80	6.60

Source: Author's personal archive.

Table 5. Average washed river sand

Concrete strength table - Medium washed river sand 10/05/15							
Series	Feature	Vol. Water (l)	A/C factor	Slump (cm)	Average strength (MPa)		
					7 days	14 days	28 days
1	01:01:02	1.7	0.43	10	13.13	13.10	15.82
2	1:11/2:2	1.7	0.43	6	21.17	20.15	26.20
3	01:02:02	1.9	0.48	8	16.54	19.4	24.35
4	1:2:21/2	2	0.51	7	13.56	18.26	23.66
5	01:02:03	2.2	0.56	6.5	13.15	16.83	18.40
6	1:21/2:3	2.2	0.56	6	11.93	16.83	16.55
7	01:03:03	2.6	0.66	8	9.87	12.03	14.05
8	01:03:04	2.9	0.74	7.5	7.86	9.08	11.90
9	01:04:04	3.6	0.92	6.5	6.54	9.05	10.45
10	01:04:05	3.9	0.99	7	4.55	6.82	7.60
11	01:05:05	4.6	1.17	8	2.95	4.06	5.35

Source: Author's personal archive.

An important issue that may arise is the possible application of additives, which are present in almost all concrete produced by concrete companies and can alter the properties of the concrete, such as final strength, workability, drying time, etc. This study did not focus on the application of additives, as it sought a general, broad study that would meet the possibilities of concrete production and the traditional materials used.

However, in both cases, the ratio of the first series is 1:1:2, which exhibits a highly porous "crushed" concrete in the sample, indicating a significant decrease in the average resistance of the sample. Therefore, this ratio was discarded when preparing the final form to be submitted. For this reason, this ratio was discarded in the preparation of the final table that will be presented.

The other results are in line with expectations, with average resistance values closer to the actual situation of the aggregates used and from the studied region, while highlighting the practical aspects of curing the specimens, which will not occur in engineering works as required by Brazilian regulations for curing.

The use of outdated tables and references without technical evaluation of the high variability in mixture compressive strength (caused by aggregate extraction locations and binder types), combined with neglected verification of critical curing steps for proper concrete hydration, may lead to structural deterioration. Therefore, the table below is presented as a final summary of the work, aiming to present to the civil engineers of the Teófilo Otoni region the average strength values of 10 commonly found mixes:

Table 6. Final table

Concrete dosage table based on aggregates from the teófilo otoni region – mg - (Cement CPIII-40-Rs)								
Medium washed river sand					Medium artificial sand (Gneiss)			
Stroke in Volume	Vol. Water (l)	A/C factor	Slump (cm)	28 days MPa	Vol. Water (l)	A/C factor	Slump (cm)	28 days MPa
1: 1 1/2:2	1.7	0.43	6	26.20	1.55	0.39	6.5	33.08
1:2:2	1.9	0.48	8	24.35	1.5	0.38	8	32.70

Concrete dosage table based on aggregates from the teófilo otoni region – mg - (Cement CPIII-40-Rs)								
	Medium washed river sand				Medium artificial sand (Gneiss)			
Stroke in Volume	Vol. Water (l)	A/C factor	Slump (cm)	28 days MPa	Vol. Water (l)	A/C factor	Slump (cm)	28 days MPa
1:2:2 1/2	2	0.51	7	23.66	1.75	0.45	6	25.85
1:2:3	2.2	0.56	6.5	18.40	2.21	0.56	6.5	19.60
1:2 1/2:3	2.2	0.56	6	16.55	2.4	0.61	8.5	17.80
1:3:3	2.6	0.66	8	14.05	2.3	0.59	9.5	16.65
1:3:4	2.9	0.74	7.5	11.90	2.3	0.59	8.5	13.40
1:4:4	3.6	0.92	6.5	10.45	3	0.76	6	13.00
1:4:5	3.9	0.99	7	7.60	3.2	0.82	6	9.30
1:5:5	4.6	1.17	8	5.35	3.5	0.89	6.5	6.60

Source: Author's personal archive.

In comparison, the resistances found in the specimens with crushed sand were higher. One possible explanation may be associated with the amount of organic matter incorporated into the mix. Washed river sands are sedimentary materials and immersed in a large amount of organic matter, which generally comes in larger quantities than artificial sands, which come from the crushing of rocks, in this Gneisses study. In addition, other factors may be associated with this increase in resistance, such as the variation in water absorption by the particles.

Regarding the amount of water applied, the use of larger volumes in concrete produced with crushed aggregate is justified by the high porosity of the material. Suman and Srivastava (2015) demonstrated that the use of this type of aggregate reduces the slump value in the tests due to the greater water absorption capacity compared to natural washed sand.

Anil et al. (2015) also studied the use of crushed sand in concrete and found good mechanical properties and the possibility of replacing washed sand, which in some regions has become less available. Both Anil et al. (2015) and the studies by Anitha Selva Sofia et al. (2013) show that crushed sand improves the mechanical characteristics of concrete when used together with super plasticizers, further increasing the possibilities with this material, which were already very promising in the tests carried out in this research. This may also be a possible alternative solution for the safe disposal of stone waste (Adanagouda et al., 2015).

4. Conclusion

Research in the construction sector is as necessary as in any other field of knowledge, especially when considering its importance, practical applicability, emerging needs, and region-specific challenges in building operations, as demonstrated in this study.

It can be concluded that the preparation of the concrete mix and dosage table met expectations, as it elucidated and provided a systematic, applicable and pioneering study in the region of Teófilo Otoni/MG, which evaluated aspects that are rarely observed. Knowing and making regional aggregates public allows for better predictions of resistance and reduces the risk of errors and possible pathologies in structures, in addition to generating greater questions and discoveries that can improve the construction methods used regionally.

It is important to remember that due to its experimental nature, the final dosage table displays the compressive strength values obtained based on a predetermined mixture, which results in a lack of some common load requirements in the project, such as 20 MPa. However, they represent the basis for adjusting the mixture and also allow for the preparation of increasingly accurate studies.

By including mixes (in volume), slump, water volume, A/C ratio and final strength at 28 days, a result was obtained that can become an important reference in the production of structural or non-structural concrete for users of the materials studied.

Finally, the good quality of the aggregates, especially the crushed ones, found in the city of Teófilo Otoni was verified, presenting an alternative to regional enterprises in the sector both in the choice of materials and in a possible shortage of natural aggregates, a trend seen in many parts of the world.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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