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Construction Waste Used as Fine Aggregates in Non-structural Concrete

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Abstract- The construction industry has grown significantly in the last 20 years in Latin American countries, mainly in Brazil. However, it is a sector with large waste production due to the techniques and construction systems used. Therefore, the objective of this work is to investigate an appropriate purpose for the construction waste (CW); incorporating small aggregates in non-structural concrete was the main focus. The study was carried out in two stages: aggregate analysis and concrete tests, based on Brazilian standards and in accordance with international standards. The aggregate analysis identified that the CW has medium sand granulometry, being favorable to concrete use, especially in regions where the natural sand is fine and requires a higher binder consumption. Regarding the concrete's mechanical strength, a concrete sample with 50% being CW, a 3.6% strength gain was obtained compared to a concrete sample with a 0% ratio of CW. In the concrete mixtures with 75% and 100% ratios a 13% decrease in strength was observed. Higher water absorption was observed in the mixtures with more recycled aggregates due to the material's porosity. Nevertheless, the absorption of the sample with 100% recycled material, at 72 hours, was 4.03%, being below the 10% limit, given by the NBR 6136.

Keywords- *Granulometry, Mechanical Strength, Water/Cement, Civil Construction*

I. INTRODUCTION

The construction sector has grown significantly in the last 20 years in Brazil, similar to what has happened in Latin America. The growth was around 3.5% by 2014, generating approximately 40,154 jobs [1], before the civil construction crisis. Despite positive economic impacts, it is the largest sector in demand for natural resources for its activities, consuming approximately 20 to 50% of these resources. As in any industrial process, the use of materials produces a large amount of waste, which needs to be administered correctly [2]. Construction and Demolition Waste (CDW) corresponds to 67% of the Urban Solid Waste (USW) in mass, corresponding to an amount of 68.5 million tons per year [3,4]. This amount of waste generates serious public health problems and visual pollution to the society at large when discarded incorrectly [5].

Recycling materials in the construction sector is a possibility and is capable of conceiving great benefits, such as reducing the consumption of natural resources considered as non-renewable [3] and improving the management of waste disposal, in favor of a decrease in the amount of materials generated [6]. In Brazil, recycling the mineral portion of CDW/CW has not been explored [7]. Even in Europe, where there are countries with recycling rates above 70%, most of this fraction is sent to level land or sub-bases of roads and are hardly returned to the construction sector as aggregates for use in concrete and mortars [8]. Proposing and studying sustainable alternatives by replacing natural aggregates with inputs that can be recycled is of great importance, especially in regions where there are difficulties or lack of natural aggregates or there is a housing deficit, raising the costs of housing [9]. The application of these materials in non-structural concrete and mortars becomes a socially and economically viable solution [5].

Concrete is classified as the most important structural material in civil construction, being only behind water [10]. Research states that worldwide concrete consumption is around 5.5 billion tons per year, where the largest portion of raw material for concrete production is extracted from natural resources [11]. Although concrete is indispensable for the building process, its constituents cause several negative impacts to the environment, since they are removed from nature on a large scale and are considered as limited resources. However, it is possible to reduce these impacts by incorporating recycled aggregates in the concrete production [12].

Through research by Martins (2008), with different types of sand with various granulometries, it is possible to observe the interference of granulometry in concrete production, where it was concluded that when the sand is finer, the water/cement ratio is altered, intervening in the workability of the concrete. In addition, there is a reduction in the mechanical strength of the product and it demands a greater amount of cement in the production, which generates a higher cost [13]. In this sense, the sand, when thin, can become a local problem and the purchase of coarser sand from a further region is necessary, increasing the final cost of the construction. Thus, the use of recycled sand as an alternative to the local deficit is an opportunity [14]. In this approach there are few studies, Pedrozo (2008), for example, used fine recycled aggregates with the amounts of 25%, 50%, 75% and 100%, and observed that the compressive strength varied 0.33 MPa between the values of 25 % and 50%, and there was a small reduction when replacing 75% of the natural aggregates with recycled [15].

Therefore, the objective of this study was to use fine recycled aggregates and to evaluate performance in manufacturing non-structural concretes, with focus on granulometry and mechanical strength, but also on the water/cement ratio and water absorption.

II. MATERIAL AND METHODS

The study was carried out in two stages: (a) aggregate analysis and (b) concrete testing. The recycled aggregates used comes from the Progemix Recycling Plant, located in the municipality of Campo Grande - MS, most of which is of cement origin from concrete remnants and mortars. However, it presents a small amount of clay from ceramic pieces. For the production of the test specimens, CP II E - 32 cement was used, due to its availability in the market, gravel with dimensions of 4.75 mm to 25 mm and fine sand found in the region were also used. For the experimental dosage, four samples with 0%, 50%, 75% and 100% of recycled aggregates were analyzed, and 12 cylinders were molded for each ratio to evaluate the concrete's mechanical strength and absorption. The concrete ratio was determined through the initial parameters of 15 MPa and slump 60 ± 10 mm. This aggregate analysis was performed in triplicates.

A. Aggregate analysis

The granulometric analysis of the fine aggregates, both natural and recycled, was carried out according to the NBR 7217, finding the granulometric curve, fineness modulus and maximum aggregate size [16]. The materials used were: a scale, steel brush and set of sieves (4.8, 2.4, 1.2, 0.6, 0.3, 0.15 mm) with the bottom sieve pan. The maximum aggregate size was defined by the mesh opening of the sieve, where the aggregate presents a retained percentage accumulated equal to or less than 5% of the total mass.

The aggregate granulometry was found according to the NBR 7217 [16], where the number of aggregates that passed through the sieves (25; 19; 9,5; 4,8; 2,4; 1,2; 6; 0.3, 0.15 mm) and the bottom sieve pan were analyzed. The maximum aggregate size and the fineness modulus were also determined. The procedure and calculations were the same for the fine and recycled aggregates.

The fine aggregates' specific mass was found according to the NBR 9776, Chapman's flask method [17]. A scale with a precision of 1 g, 500 g of aggregates and the Chapman flask was used for each result. The specific mass was found by the following Equation (1):

$$\rho = \frac{M_d}{L - L_0} = \frac{500}{L - 200} \qquad (1)$$

Where:

ρ = specific mass of the fine aggregates ($kg.dm^{-3}$);

M_d = mass of the dried material (500g);

L_0 = initial flask reading (200 cm^3);

L = final flask reading (cm^3).

The specific mass of the coarse aggregates was determined with the test tube. The analysis compared the mass of the test tube full of water (200 mL), with the test tube full of water + 500 g of aggregates, to calculate the specific mass of the aggregates, by Equation (2):

$$\rho = \frac{M_s}{(M_1 + M_s) - M_2} \qquad (2)$$

Where:

ρ = specific mass of the coarse aggregates($kg.dm^{-3}$);

M_s = sample mass (g);

M_1 = mass of the test tube + water (g);

M_2 = mass of the test tube + water + sample(g).

The unit mass of the fine and coarse aggregates was found in their loose state (μ_1) according to the NBR 7251 [18]. To find the unit mass in the compacted state (μ_2) according to NM 45 [19], the material's unit mass was found according to Equation (3):

$$\mu = \frac{M_T - M_C}{V} = \frac{M}{V} \qquad (3)$$

Where:

μ = unit mass ($kg.dm^{-3}$);

M_T = container + sample mass (kg);

M_c = container mass (kg);

M = sample mass (kg);

V = container volume (dm^3).

The moisture content of the fine aggregates, both natural and recycled, was found according to the NBR 9775 [20] using the Chapman flask, with moisture being a factor that influences the concrete's water/cement ratio. The procedure was performed in the same manner as the specific mass by using the Chapman flask. Surface moisture in the small aggregate, expressed as a percentage, was calculated by Equation 4:

$$MC = \frac{100\,[500 - (L-200)\,\gamma]}{\gamma\,(L-700)} \qquad (4)$$

Where:

MC = moisture content (%);

500 = humid test sample (g);

200 = initial water level added to the flask (cm^3);

L = reading of the aggregates with the most water recorded on the flask's scale (cm^3);

700 = sum of the water level and the humid aggregates;

γ = specific mass of dry material ($kg.m^{-3}$).

The moisture content of the coarse aggregates was established according to the NBR 9775, by the oven drying method [20]. The procedure was based on obtaining the humid sample's mass, placing it in the oven on a container, and after a determinate time the dry aggregate's mass was found. The total moisture of the aggregates was calculated by Equation 5:

$$U = \frac{Mh - Md}{Md} \times 100 \quad (5)$$

Where:

MC = moisture content (%);

M_h = mass of the humid sample (g);

M_d = mass of the dried material (g).

The percentage of powdery material for the three types of aggregates was found according to the NBR NM 46 [21], which was carried out by the washing method. Water was added to the aggregate sample in a container and was shaken to suspend the powdery material, then the water was removed and the aggregates were washed in the sieve until the water was light in color. Finally, the aggregates were taken to the oven and after drying, the dry aggregates were weighed. The percentage of powdery material was defined by Equation (6):

$$m = \frac{(m_i - m_f)}{m_i} \, x\, 100 \quad (6)$$

Where:

$m = fine\ material\ that\ passes\ through\ the$

$0.075\ mm\ sieve\ per\ wash (\%)$

m_i = original mass of the dried sample (g);

m_f = mass of the dried sample after washing (g).

B. Concrete tests

The concrete ratios were found according to the Brazilian Association of Portland Cement's (ABCP) [22] method, where the strength of 15 MPa was adopted because the concrete was non-structural, and the slump was 60 ± 10 mm. In order to maintain the slump constant, the water/cement ratio of the slump was varied, by measuring the aggregates and cement by mass, and the water by volume, discounting the aggregates' moisture content for correction, according to the NBR 12655 [23].

The tests for the concrete analysis were based on the Brazilian Technical Standards, being that the molding and curing were based on the NBR 5738 [24]. After 24 hours from the time the specimens were molded they were unmolded, identified and stored in a humid chamber.

The slump test was performed, which confirmed the concrete's slump according to the NBR 7223 [25]. The compression test was performed according to the NBR 5739 [26], and the cylinders were tested for strength on the 7^{th}, 14^{th} and 28^{th} day. The strength of the test pieces was measured by an EMIC hydraulic press, model PCE100C; NO8627; NS235, with calibrated scales at 1000 kN.

The water absorption in the concrete was found by immersion as described by the NBR 9778 [27]. First, three specimens were produced and the mass of each was determined in the air. They were put in the oven until a constant mass was maintained and then finally were taken to the immersion vessel, where the sheet of water was constantly 5 mm above the underside of the specimens. The mass of the specimens was determined 24 h, 48 h and 72 h after they were placed in the vessel.

III. Results and discussion

A. Analysis of the physical properties of the aggregates

1) Granulometry

With the percentage retained by each sieve, the granulometric curvature of the coarse aggregates was obtained, with a maximum aggregate size of 25 mm and a fineness modulus of 7.14 mm, according to the gradation 1 in Fig. 1.

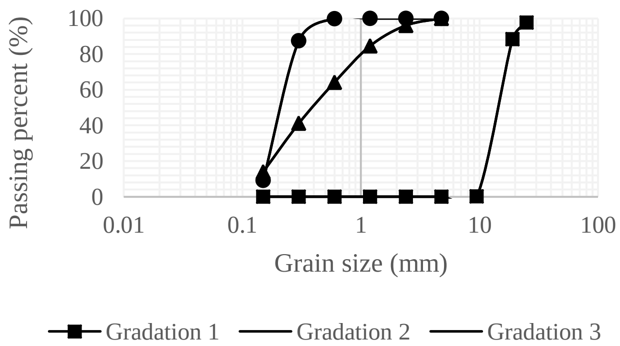

Figure 1. Granulometric curve of the aggregates.

The maximum size of the aggregates is used to determine the cement consumption and is also a factor of influence for the workability [28]. Araujo, Gomes, Weber, Prudêncio Junior (2011) [29] state that the coarser the aggregate size is, the lower its cement consumption is and the smaller quantity of fine aggregates there are for good plasticity.

The average percentage of recycled sand size is displayed in a granulometric curve, gradation 2 (Fig. 1), which shows medium sand with a fine portion, and a fineness modulus of 2.08 mm and a maximum aggregate size of 2.40 mm. The natural sand used presented the granulometric curve, gradation 3 (Fig. 1), classified as fine sand, with a fineness modulus of 1,03 mm and a maximum aggregate size of 0,60 mm.

In a study carried out by Bastos (2002) [30] with fine recycled aggregates, a characterization of coarse sand with a fine portion and a very fine natural sand with a fineness modulus of 1.12 mm was found, observing that the very fine granulometry of the small aggregates interfere with the cement dosage for the concrete production. When analyzing recycled sand, Gomes (2016) [31] found the granulometry to be composed of medium sand and also with a fine portion, and it was observed that the higher percentage of the find sand raised the water/cement ratio in the concrete. Martins (2008) [13] observed that the small aggregate with a higher fineness content influences the reduction of concrete, and the higher the percentage of fine sand the lower the reduction, thus increasing the water consumption and consequently the consumption of cement

2) Specific and unit mass

The values from the specific mass analysis, the unit mass in the loose and compacted state, of the natural and recycled aggregates are presented in Table I.

TABLE I. SPECIFIC AND UNIT MASS (KG.DM-3) OF THE AGGREGATES.

Aggregate	ρ	μ_1	μ_1
Coarse	2.88	1.42	1.54
Fine recycled	2.46	1.24	1.41
Fine natural	2.66	1.38	1.53

In an analysis done by Fonseca, Ribeiro Junior, Barbosa (2016) [32] and Bastos (2002) [30] of natural aggregates' specific mass, values of 2.81 kg.dm-3 and 2.83 kg .dm-3 were obtained respectively, thus observing small variations in the specific mass values studied.

When studying fine recycled aggregates, Fonseca, Ribeiro Junior, Barbosa (2016) [32] reached the specific mass value of 3.93 kg.dm-3, being that the aggregates studied had a predominant source of ceramic material. Bastos (2002) [30] obtained the result of 2.94 kg.dm-3 and Gomes (2016) [31] obtained 2.52 kg.dm-3, values closer to that found in this study, which was 2.46 kg. dm-3. The aggregates studied were mostly cementitious, similar to this study's material.

When evaluating the specific mass of the fine natural aggregates, the value of 2.66 kg.dm-3 was obtained. In a study conducted by Fonseca, Ribeiro Junior, Barbosa (2016) [32] a value of 2.41 kg.dm-3 was found, Gomes (2016) [31] characterized the specific mass with a value of 2.64 kg . dm-3 and Bastos (2002) [30] obtained the value of 2.63 kg.dm-3. Thus, values with small variations were found.

When comparing the specific mass of the natural sand with the recycled sand, a lower value for the recycled material was observed, as it was also observed in a study by Gomes (2016) [31], who carried out the analysis with sand from the same region as this study.

As observed by Lima (1999) [28], the specific mass of the recycled aggregates is lower than the natural ones, due to the porosity of the material, verifying that the smaller the specific mass of the aggregate is, the lower its mechanical strength is and the greater its water absorption is, factors that influence concrete's durability.

In relation to the unit mass in the loose and compacted state of the aggregates, it should be noted that there is no standard with specified limit values. However, Basílio (1995) [33] evaluated that most of the normal aggregates for the production of normal concrete have a unit mass close to 1.50 kg.dm-3.

The unit mass in the loose state reached a value of 1.42 kg.dm-3 for the coarse aggregates, 1.21 kg.dm-3 for the fine recycled aggregates and 1.38 kg.dm-3 for the fine natural aggregates (Table I). If we compare these results with other studies it is apparent that the values are similar. Bastos (2002) [30] found a unit mass of 1.60 kg.dm-3 for the coarse aggregates, 1.64 kg.dm-3 for recycled sand and 1.49 kg.dm-3 for natural sand, and in a study by Meier (2011) [34], in which he analyzed only natural aggregates, a result of 1.45 kg.dm-3 through an average of 5 samples was obtained.

For the unit mass in the compacted state, approximate values close to those found in the loose state were obtained, being 1.54 kg.dm-3 for the coarse aggregates, 1.41 kg.dm-3 for the fine recycled aggregates and 1.53 kg.dm-3 for the natural aggregates (Table I). Research done by Fonseca, Ribeiro Junior, Barbosa (2016) [32] with only coarse aggregates presented a unit mass of 1.40 kg.dm-3.

It can be observed that both the unit mass results in the loose state and in the compacted state, for the recycled aggregates have lower values compared to the natural aggregates due to the porosity of the recycled material, and as Paula (2010) concluded the porosity of the material leads to greater water absorption [5].

3) Moisture content

The moisture content of the aggregates was determined, being: 1.96% for the coarse material, 8.57% for the fine recycled material and 5.16% for the fine natural material (Table II). In a study by Barbosa and Silva (2016) [35], a moisture content of 1.29% was found for the coarse aggregates, a value close to that obtained in this study. In regards to moisture in fine aggregates, Bastos (2002) [30] identified 3.75% in recycled sand and 3.5% in natural sand. In both results, the moisture content in the recycled material is higher than the natural material due to its high porosity.

TABLE II. MOISTURE PERCENTAGE OF THE AGGREGATES.

Aggregates	MC (%)	m (%)
Coarse	1.96	0.99
Fine recycled	8.57	5.18
Fine natural	5.16	3.07

According to Kruguer and Grande (2013) [36], the moisture analysis of the aggregates for concrete dosage is of relevant importance, since its value directly influences the water/cement ratio, which provides adequate workability. If there is a greater consumption of water than necessary, it may cause a decrease in the concrete's strength.

According to the NBR 7211 (2005) [37], the powder content of fine natural aggregates can range up to 5%, for fine recycled aggregates it can range between 5% to 7% and the maximum powder limit for coarse aggregates is 1%. Therefore, the values found are within the allowed limits, as presented in Table II.

Samples tested in a study by Bastos (2002) [30] display 3% powder in natural sand and 3.5% in the recycled sand and, in tests carried out by Meier (2011) [34], the average percentage of powder in natural sands was around 3%, values close to those found by other authors. According to a study conducted by Basilio (1995) [33], when there are considerable values of powdery material, it is necessary to add more water to obtain a good workability, being that fine material is responsible for increasing the retraction of the concrete and to decrease its strength due to changing the water/cement ratio of the concrete.

B. Concrete Testing

1) Ratio

The concrete ratio was found to be 1: 1.93: 3.88: 0.58, observing a variation in the water/cement ratio (Fig. 2), as the recycled aggregate was added and the slump was constant.

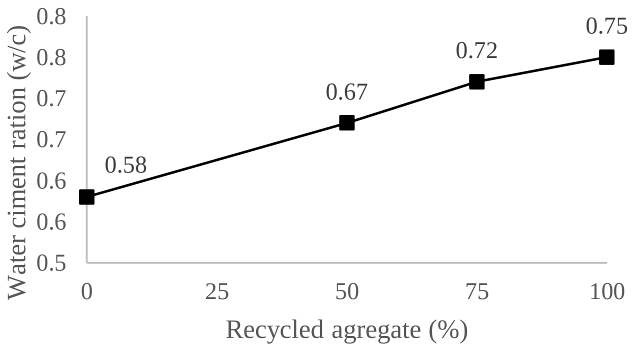

Figure 2. Variation of the water/cement ratio in relation to the addition of recycled aggregates.

With the values obtained, an increase in the water/cement ratio is observed as a function of the percentage of recycled aggregates added. Barbosa and Silva (2016) [35] attributed this increase of the water/cement ratio to the porosity of the recycled aggregates. Lima (1999) [28] observed that the water/cement ratio increased when recycled aggregates were added compared to concrete with natural aggregates, adding that the increase to the porosity of the material and also to the significant amount of fine material presented by the recycled aggregates (Lima, 1999). Paula (2010) [5], also noted an increase in water consumption due to the presence of fine material in the granulometry of their recycled sand and the large absorption of the aggregates due to porosity.

2) Compressive strength

When evaluating the concrete's compressive strength, a variation in strength is observed regarding the increase of recycled material used (Fig. 3).

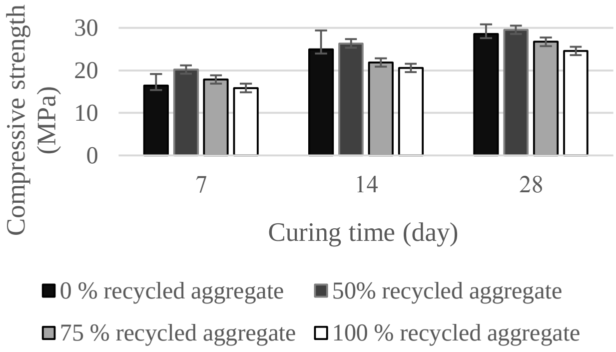

Figure 3. Average concrete strength for different ratios.

It is possible to notice that when the mixture has a ratio of 50% recycled aggregates, a larger average strength to compression was reached, being 50% higher than the initial 0% value of the recycled aggregates. However, when incorporating ratios with 75% and 100% of the recycled material, a reduction of about 12% was obtained when compared to the ratios with 100% natural material, a figure higher than 15 MPa, the initial calculated value, was obtained.

In studies carried out by Frondistou - Yannas (1997) and Topçu and Gunçan (1995) [38,39], it was concluded that by keeping the slump constant, there was a change in the water/cement ratio, where it increased as the recycled aggregates were added and consequently there was a decrease in mechanical strength. This decrease in mechanical strength was also observed in the recycled aggregates with a ratio of 75% and 100%.

It was observed that even with the increase of the water/cement ratio, the strength values were increasing in the mixtures with ratios between 0% and 50% of recycled material incorporated. Accordingly, in a study analyzed by Gonçalves (2001) [40], the gain of mechanical strength is attributed to the quality of the recycled materials used. Bastos (2002) [30] points out that fine sand granulometry influences mechanical strength loss. In their analyzes it was found that when replacing fine sand with artificial sand in the range of 30% to 50%, the highest strength was reached due to the better granulometric distribution. Pedrozzo (2008) [15] observed the best granulometry distribution when substituting between 25% and 50% of the natural aggregates for recycled and also observed the best strength between these values. Thus, since the granulometry of recycled aggregates in this study was classified as average, this makes it relevant for increased strength, being in agreement with the outcomes found in the results.

Salem and Burdette (1998) [41] consider in their studies that due to the rough texture and angular shape of recycled aggregates a better adhesion and interlocking between the cement paste and the aggregates is provided, aiding the concrete's mechanical strength. In addition, Bastos (2002) [30] and Gonçalves (2001) [40] show that the greater the substitution of the recycled aggregates is for the natural aggregates, the greater the portion of fine material is present, which generated a strength reduction, as observed in the 75% and 100% ratios.

3) Water absorption test

When evaluating the concrete's absorption for its four ratios, it can be observed that there was an increased water absorption as the recycled aggregates were increasingly incorporated (Fig. 4).

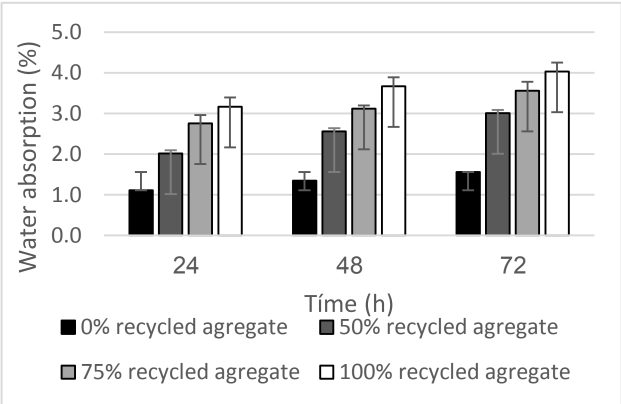

Figure 4. Average concrete absorption.

The water absorption was increased accompanying the percentage of recycled material added, observing that when incorporating 100% recycled aggregates the absorption was 2.58 times greater than the concrete in natura. Pedrozzo (2008) [15], in his study, obtained an absorption two times greater when incorporating 100% recycled aggregates, attributing this increase to the small aggregates due to their porosity. Bastos (2002) [30] studied concrete absorption in samples, which presented a variation of 2.8% absorption between the ratios with 0% and 100% of recycled aggregates and observed that the lower the water/cement ratio, the lower the water absorption of the concrete, considering that the higher the cement quantity, the lower the void indexes, and consequently the lower the absorption. However, when incorporating 100% of recycled aggregates, it is possible to notice the increase of the concrete absorption, presenting a value of 4.03%. Although this is superior to concrete with 0% recycled aggregates, it is lower than the 10% limit established by the NBR 6136 for concrete with natural aggregates.

IV. CONCLUSION

It can be concluded that the coarse aggregates used have a favorable particle size for the least amount of binder needed. The fine natural aggregates show fine granulometry, being unfavorable to be used, since they require a greater binder consumption. The recycled aggregates have a medium sand granulometry, thus being more favorable for concrete use, but presents a significant amount of fine material, which also leads to higher cement consumption.

In relation to the aggregates' specific mass, it was observed that when comparing the natural aggregates with the recycled, the latter presents a specific mass of 2.46kg.dm-3 being less than the natural aggregate's specific mass of 2.56kg.dm-3, due to its porosity, this is a dominant factor for concrete strength and durability. Also analyzing the specific mass in loose and compacted states, lower values are observed in relation to the recycled material, also due to the material's porosity.

It was found that the recycled material had a moisture content of 8.57%, being higher than the natural material with 5.16%. In addition to determining the proper dosage, the powder content is also critical, directly interfering with the water/cement ratio, where the recycled aggregates presented 5.18% and natural aggregates 3.07%. Thus, it is well known that concrete's water/cement ratio is directly related to the amount of recycled material that is added in it, since the increased consumption of concrete is due to the porosity and fine material present in recycled aggregates.

By observing the concrete's mechanical strength, substituting 50% of the natural aggregates for recycled, a strength gain was obtained when compared to the initial ratio of 0%, attributing this gain to the bettered granulometric distribution. On the other hand, in the ratios with 75% and 100% recycled material, a 13% strength decrease was observed due to the increase of fine material.

From the water absorption test, an increase of 2.58% was observed when comparing the mixture without recycled material with 100% recycled material. This gain was due to the porosity of the recycled material and to the water/cement ratio, which increased as the amount of recycled material was added. In spite of this, the absorption of the sample with 100% recycled material at 72 hours was 4.03%, being below the 10% limit, given by the NBR 6136.

It is concluded that the use of non-structural concrete with recycled aggregates becomes feasible according to water absorption and mechanical strength parameters. The swelling curve analysis for fine recycled aggregates is suggested as a recommendation for future studies, where the variation of the aggregates' volume will be observed as a function of its moisture content.

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