

Analysis of the Impact on Axial Compression and Diametric tensile strength of concrete using recycled fine aggregate

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Abstract—Due to the current environmental crisis and the improper disposal of construction and demolition waste (CDW), the incorporation of these as aggregates in the manufacture of concrete is presented as one of the main alternatives for the proper disposal and consequent recycling of it. Such use requires technical knowledge regarding possible changes in the properties of the final product. Thus, this study aims to compare some of the main properties of conventional concrete with the executed one through the incorporation of recycled fine aggregates (RFA). The aggregate was collected in the recycling factory at FUTURE, a company located in Cascavel, Paraná – Brazil. Four mix ratios were elaborated, distinct by the replacement percentages of the conventional fine aggregate to the recycled one (0, 20, 40 e 60%), where the workability, the water absorption of the concrete, the axial compressive and tensile strength were evaluated. Thus, the increase of the workability and the absorption were verified with the highest degree of replacement as well as the reduction of the axial compressive and tensile strengths.

I. INTRODUCTION

With the growing environmental and sustainable debate, the emergency is evident of the alarming problem related to the disposal of waste, whether domestics, industrials or mainly from civil construction. In the case of Paraná, in more than 90% of the state territory the disposal of construction and demolition waste (CDW) ends up being done in the wrong way [1]. Destined primarily together with other urban waste for landfills, which is commonly improper. Among the main reasons that trigger such attitudes, one can cite the lack of education for the community of workers in the sector, as well as the lack of supervision by regulatory and competent bodies [2]. In this way, solutions capable of making the reuse of such waste possible are tested to the point of encompassing the production process, consumption and disposal in an ecologically correct cycle and economically

advantageous. A possible alternative to preserve the environment is the reuse of these residues as aggregates in the manufacture of cementitious materials.

In Brazil, the National Council for the Environment (CONAMA), in its resolution number 307/02 [3], together with n° 448/12 [4], deals with the issue of the disposal of waste from civil construction. On the 10th article of the resolution no. 307/02 [3], it is verified the obligation of recycling or correct reuse as aggregate of the residues belonging to class A. In this class include ceramic components, mortars and concrete from construction, demolition, repair and renovation of buildings, as well as waste from the handling of precast concrete parts. Thus, it is observed that one of the destinations for the reincorporation of such aggregates is in the production of recycled concrete. At the municipal level, law No. 6663 of

December 6, 2016 defines in its Article 1, the possibility of using in public works these aggregates from waste belonging to class A, originating from civil construction. Therefore, a minimum percentage is stipulated for this use, being 10% of the total materials used in each work [5]. Thus, the incorporation of these aggregates into the concrete consists of one of the main alternatives for such percentage to be accomplished.

Thus, the objective of this study is to verify the feasibility of using RFA (recycled fine aggregate) as a substitute for the conventional fine aggregate in the manufacture of concrete. Since, the axial compressive and diametral tensile strengths, as well as the workability and absorption of the cementitious material consist in the parameters used to check whether the recycled aggregate meets expectations.

II. LITERATURE REVIEW

There are several problems involving the subject term, especially when dealing with the influences of these residues on the properties of the concrete. Considering or taking into account that a large part of the concrete volume consists of aggregates in general, it is concluded that both their chemical and physical properties will directly interfere in the performance of the matrix material [6]. With regard to this executed concrete using recycled aggregates from the CDW, the main obstacle is the heterogeneity of the analyzed component. Since in most cases the CDW are provided from ceramic materials such as bricks, tiles, porcelains, glass, to grains from cement, through the remains of mortar and the original concrete of the work. In this way it is difficult to analyze such an aggregate in relation to the specific strength, because each parcel of material constituting the whole may present distinct characteristics.

Based on the literature of the subject, recycled aggregates have higher porosity when compared to natural ones, due to the heterogeneity of their constituents, which also gives them a higher hygroscopic [7]. Due to this fact, the same author also reports on the need for a pre-moistened of these aggregates, in order to reduce the unbalance of the water-cement (w/c) fraction of the final mixture.

Many studies discuss the changes caused by recycled aggregates in the general properties of concrete. Regarding workability, the literature shows a reduction in this property when recycled coarse aggregates are incorporated into the cement matrix [8]. Because of the subjective character, we consider the workability of the samples as a sum of two parameters, namely: "Slump Test" and the quantity of fine aggregate particles present in the cement mass. However, with regard to the fine aggregates, an increase of the slump-test can be seen as the highest amount of RFA (*recycled fine aggregate*) in the mixture. A possible explanation would be

that this effect may occur due to the different particle-size curve presented by the heterogeneous recycled material, since the increase in the number of fines of the mixture promotes the lubrication effect of the largest particles [8]. The same author observed an increase of about 17% in the workability of the paste by replacing 50% of the conventional fine aggregate by RFA (*recycled fine aggregate*).

Datas indicate that by incorporating recycled aggregates, the concrete in its hardened state presents a higher water absorption compared to that produced with natural aggregates. By using a coarse-grained crusher run, it is possible to observe a gain of 42 and 65% in this property for concretes with 25 and 50% of substitution, respectively [9].

In relation to the compressive strength, Lovato [10] used in his study a recycled fine aggregate passing in the 4.8 mm mesh sieve, constituted of concrete waste, mortar, red and white ceramics, and natural rocks. The author found a reduction of 4.8, 9.6 and 14.4% for concretes with 25, 50 and 75% substitution, respectively. The following values were found by the author: 25 MPa for the reference concrete, 23.8 MPa for 25% replacement of conventional fine aggregate by RFA (*recycled fine aggregate*), 22.6 for 50%, and 21.4 MPa for 75%.

Evaluating the tensile strength by diametral compression, Leite[8] verified a direct proportionality between the RFA (*recycled fine aggregate*) content and the tensile strength of concrete. However, the author points out the possibility of this effect being altered by the adopted w/c ratio, and there may even be a decrease of the strength as higher percentages of RFA (*recycled fine aggregate*) in the mixture. It is also worth mentioning that in general terms, the tensile strength of concrete usually corresponds to 10% of its compressive strength [11].

Considering the importance of the knowledge about the effects of aggregates in concrete, this study justifies itself through the experimental analysis of some of the most important influences of the recycled fine aggregate (RFA) in the concrete obtained by its incorporation. The analyses performed are primarily intended to investigate both compressive and tensile strengths, as well as the absorption and workability of the proposed mixes for different concentrations of the recycled fine aggregate (RFA) in the concretes.

III. METHODOLOGY

3.1 Materials used

In order to make concrete specimens for the present study, several materials were used, namely: drinking water, Portland Cement CP II F-40 (type II, Moderate Sulfate Resistance), gravel ($9.5 < d < 19$ mm) from basaltic, washed river sand with medium grain (natural aggregate) and recycled sand from crushing of CDW.

3.2 Laboratory equipment and utensils

The procedures, on the other hand, are summarized by the elaboration of the mixing ratio for concrete dosing and the molding of cylindrical specimens for the execution of tests on the material's properties. The laboratory tools used for making the specimens can be listed as: Various laboratory glassware, precision balance SOLOTEST (± 1 g), MOTOMIL Mb 150l portable concrete mixer, 20x10cm metal molds to mold the specimens, buckets, plastic trays, mold release agent from the fractional distillation of petroleum. As for the equipment with the purpose of storing the specimens and subsequent analysis, they can be listed as follows: chamber for moist curing, drinking water, hydrated lime (applied in the curing chamber), QUANTEQ hydraulic press CH 019 S 004, slump cone test, neoprene plates and discs. Besides these, it is worth emphasizing the proper use of safety equipment, such as gloves, masks, goggles, and lab coats, among other necessary items.

3.3 Control of the manufacturing processes of the specimens

Seeking for a standardization of the remaining variables, a rigorous laboratory control system was established, and several preventive measures were followed for the preparation of the specimens. The main factors to be highlighted during this step are: the entire experiment was performed within a single laboratory and at the same ambient temperature (23°C). The relative humidity of the air can be considered constant, since the room temperature controllers were always turned on two hours before the confection of the specimens.

The order of insertion of the constituents in order to obtain the proper homogenization in the concrete mixer was the same for all the elaborated mixes, namely: aggregates and 1/3 of the total water of the mixture in stirring for 5 minutes, then the total cement and the rest of the water are added concluding with another stirring of 5 minutes; to continue maintaining the standard, all specimens were molded by the same researcher. The molding followed the regulation of the Brazilian Association of Technical Standards [12], in which the dimensions of the specimens are described, as well as the concrete compaction method required for each type of mold. Thus, according to Table 3 (Number of layers for molding the specimens) present in this standard, for each specimen, 2 layers were executed

with a total of 12 strokes each, since the mold used consists of a cylinder 100mm in diameter by 200mm in height and the method of compaction was manual.

3.4 Collecting the recycled aggregate

The recycled fine aggregate was donated by FUTURE Reciclagem Inteligente and collected at the company's headquarters, located in Cascavel city - Paraná state. Future is a company that, besides performing demolitions, receives civil construction waste, separates and classifies them into different classes according to the Conama Resolution 307/02 [3]. For those class A, it performs the grinding, resulting in several by-products that can be reinserted in the construction sector. These include crusher run, crushed stone, clearst one, gravel and sand, which was used in this study.

The recycled sand obtained has a uniform granulometry, and is made up of different materials, such as brick, flooring, porcelain tiles, concrete, and mortar for plastering and laying. Thus, about 1000 liters of the material were collected for further use. The raw material (Fig. 1) was obtained from productions carried out on different days, as a way to ensure product standardization, provided by the strict control performed by the company's professionals.



Fig. 1: Aggregates recycled at FUTURE (Author)

3.5 Preparation of the recycled aggregates

After collection, the recycled aggregates were transported to the laboratory to be stored in hermetically sealed plastic containers. Prior to its use, the recycled aggregate was dried in a laboratory oven for 24 hours at $105^{\circ}\text{C} (\pm 5^{\circ}\text{C})$ and then stored again in an airtight container. This moisture removal was done to ensure the same condition of the recycled material compared to the natural ones (being 0% moisture beforehand).

3.6 Preparation of the concrete mix ratio

In order to elaborate the baseline mix ratio, an axial compressive strength (F_{ck}) of 40 MPa was initially stipulated, since it is above the minimum limit for use as structural concrete. However, because of the possible variations in the manufacture and handling of concrete, a standard deviation of dosage (S_d) of 4 MPa was adopted in order to increase the desired strength (F_{cj}) to ensure that no variations occur smaller than the initial stipulated value. For this purpose, the Equation 1 was used, according to the Brazilian standard [13]. It is worth mentioning that this value of 4 MPa was selected because of the extreme caution evidenced during the research activities, since it was performed in a controlled laboratory environment.

$$f_{cj} = f_{ck} + 1,65 * S_d \quad (1)$$

Therefore, using the Brazilian Portland Cement Association [14] method of dosage and with a delimiting strength of mixing of 46.6 MPa, the final result was the following mixes: 1:2.2:3.6, with a w-c ratio of 0.61 and a slump cone test set between 9 and 10 cm. In light of this, four mix ratios were executed, with a baseline mix ratio with 0% substitution and three more using the gradual substitution of the natural fine aggregate by the recycled one in the following proportions: 20, 40, and 60%.

Because of the difference in specific mass observed between conventional and recycled aggregate, a correction of the mass of the second one was necessary. For this purpose, the equation 2 was used with the following variables: the mass of natural aggregate (M_{na}), the mass of recycled aggregate (M_{ra}), specific mass of natural aggregate (γ_{na}) and specific mass of recycled aggregate (γ_{ra}).

$$M_{ra} = \frac{M_{na}}{\gamma_{na}} \gamma_{ra} \quad (2)$$

To avoid the change in the amount of water due to greater absorption by the recycled aggregate, a pre-wetting was performed on it with an amount of water equivalent to 90% of its total absorption, as recommended by Angulo [15].

3.7 Particle size composition

Regulated by the Brazilian Technical Standard [16], the particle size composition test of the aggregates aims at classifying the material based on the dimensions of its particles, as well as the percentage that each granulometric range represents in its composition.

To do so, samples of 5 kg will be used for the test referring to the aggregates (both coarse and fine). Thus, for

the realization of such characterization, the sieves of the normal series were used in combination with those of the intermediate series.

3.8 Workability test

This was performed for the four mixes in order to observe the achieved slump for each one. For this purpose, the slump test was performed from the slump cone, which follows the regulations of the Brazilian National standard [17].

3.9 Concrete water absorption

Following the regulations of the Brazilian Standards [18], to determine the water absorption of concrete, three specimens were used per mix ratio, and these were kept in a moist curing process for 28 days. Thus, each specimen was dried in a laboratory oven at a constant temperature of 105°C ($\pm 5^\circ\text{C}$) for 24 hours and then their masses were measured.

After that, they were submerged in water for another 24h and after superficial drying, their masses were measured again. Thus, with the difference in mass observed, the absorption of the concrete in its hardened state was obtained.

3.10 Axial compressive strength test

For each of the mix ratios, tests were performed at ages of 7, 28 and 160 days after demolding, and for each age 5 specimens were used. In this test the recommendations described in the Brazilian standard [19] were followed.

The equipment used consisted of a QUANTEQ hydraulic press model CH 019 S 004 with a capacity of 100 tf. A speed of 0.45 (± 0.15) MPa/s was applied. In contrast to the capping, metallic plates and neoprene discs with 70 shore hardness and 13mm thickness were used. The use of neoprene is justified by the fact that the specimens had not been previously rectified, which could cause them to crack due to some irregularity resulting from molding.

3.11 Tensile strength test by diametral compression

Regulated by the Brazilian standard [20], it consists in obtaining the tensile strength of concrete through the result of the diametral compression test of the specimens. However, in order for the data obtained to refer to the tensile strength itself, the use of Equation 3 is necessary, which contains the following variables: tensile strength by diametral compression (f_{tD}), reached load in the test (F), diameter in mm of the specimen (d) and width in mm of the specimen (L).

$$f_{tD} = \frac{2F}{\pi dL} \quad (3)$$

In total 16 specimens were tested, 4 for each mix ratio at the age of 28 days of curing. The equipment used was the same used for the compressive strength test (QUANTEQ hydraulic press model CH 019 S 004 with a capacity of 100 tf) and a speed of 0.45 (+/- 0.15) MPa/s was also applied.

3.12 Statistical analysis of the collected data

The statistical test results in the possibility of the error of accepting or rejecting the null hypothesis, defined as type I and II errors, respectively. Therefore, the significance of 5%, adopted in Tukey's statistical test, consists in statistically safeguarding the probability of correctness in 95% of the evaluations of the null hypothesis [21]. Therefore, in order to ensure reliability to the data obtained, they were submitted to Tukey's test, where they followed the checks for their similarities and categorized into groups according to the proximity of the values. Through this analysis, the goal is to establish correlations to determine the variations caused by the replacements of the natural fine aggregate by the recycled one. It is important to point out that Student's t-test was used for the statistical treatment of the data referring to concrete water absorption, since, due to the large variance observed among the values, the use of Tukey's test is not recommended.

Student's T-test consists of a test that through statistical means focuses on whether or not to reject the null hypothesis when the test statistic (t) holds in a Student's t-distribution [22].

IV. RESULTS

In total, 88 cylindrical specimens of 10 x 20 cm were made, 22 for each mix ratio. After 24 hours of pre-curing, all were demolded, and then stored in a moist curing chamber, kept submerged in drinking water with hydrated lime at saturation. The subsequent tests performed with the deferred concretes by their respective mixes were responsible for determining the axial compressive strength and tensile strength by diametral compression, as well as the absorption. The subsequent tests performed with the deferred concretes by their respective mixes were responsible for determining the axial compressive strength and tensile strength by diametral compression, as well as the absorption. The workability was also verified, and its test being performed at the time of concrete mixing.

4.1 Particle size influence

The Fig. 2 compares the particle size distribution curves for the natural and recycled fine aggregates.

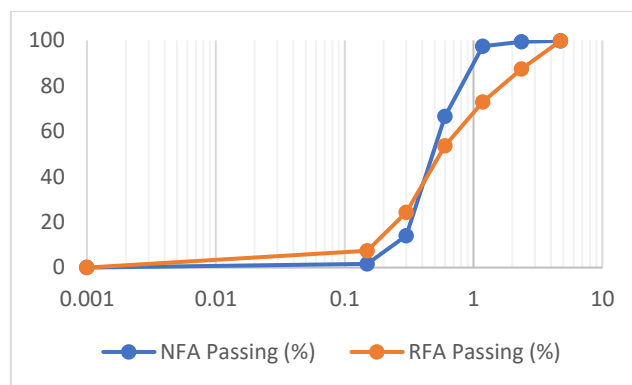


Fig. 2: Particle size distribution curves (Author)

Therefore, when analyzing the size distribution curve of the recycled aggregate in comparison to the natural one, one can note a higher number of fines, that is, a greater size distribution along the sieves. This greater number of fines, according to Cabral [23] would be a possible explanation for the increased strength of the concretes made with such alternative aggregates. Since these particles, especially the red ceramic ones, can exert a pozzolanic effect inside the mixture, which leads to an improvement in the transition zone and increases the strength of the composite [23]. Similarly, Vandhiyan[24] cites that the volume of the fine aggregate plays a key role in reducing voids in the cementitious mixture, so a sand with less volume is preferred in the realization of the same, to achieve higher strength. Furthermore, Medeiros-Junior [25] reports in his work that concretes with fine recycled aggregate had higher compressive strength than concretes with coarse recycled aggregate for the same waste sample.

Despite the possible beneficial effect portrayed above, in the present study the result was the opposite, i.e., there was only a reduction in the concrete strength as higher rates of recycled aggregate were added to the mix. Therefore, it can be concluded that the negative effect caused by the low strength of the particles of the alternative aggregate outweighs the benefits from the improvement by the effect of a greater particle size dispersion.

4.2 Workability of concrete in its fresh state

The tests performed through the slump cone indicate the slump of the different concretes right after the homogenization of the components in the mixer. The results obtained were: 9.5 cm for concrete with 0 and 20% substitution and 16 cm for those with 40 and 60% of incorporation. These data indicate that the more the natural aggregate is replaced by the recycled, the greater the slump of the concrete will be.

As explained by Leite[8], a possible explanation for this consists in the different particle-size curve of the recycled aggregate. Another factor would be the pre-wetting

performed, which may be responsible for the addition of water. The constant pre-wetting percentage of the samples was justified due to the higher water absorption of the aggregates, where when the mixes were made, the recycled aggregate consumed a lot of water in the mixture, considerably altering the w/c ratio. The most significant difference of workability lies between the concretes with 40 and 60% with respect to the others, a fact that can be interpreted by the greater mass of recycled material in these mixes with more than 40% substitution. Thus, consequently

in those concretes with a higher percentage of incorporation, a larger amount of water was used for pre-wetting.

4.3 Concrete water absorption

The tests performed for each of the mix ratios at 28 days of curing generated the results that, together with the standard deviations, can be seen in Table 1.

Table 1: Concrete Water Absorption.

Mix Ratio	Mass in saturated state	Mass in dry state	Mass difference	
% of RFA	(g)	(g)	(g)	(%)
0	3960,67±9,29	3752,67±9,98	208,00±4,32	5,25
20	3870,00±43,8	3641,33±53,3	228,67±95,6	5,91
40	3841,33±31,7	3573,00±33,4	268,33±59,5	6,99
60	3786,00±34,8	3501,33±40,1	284,67±66,4	7,52

Therefore, it is noticeable that the absorption of concrete is directly proportional to the content of replacement of natural fine aggregate (NFA) by recycled fine aggregate (RFA). There was a gain of 9.94, 29.01 and 36.86% of this property for the concretes with 20, 40 and 60% of incorporation, respectively, in relation to the mass of water absorbed by the specimens (taking the mass of water absorbed by the sample without replacement of recycled aggregate as the reference).

It is worth mentioning that, as explained in the previous paragraph, the data were presented in their absolute form, without statistical treatment and analysis using standard deviation. This choice of procedure can be understood because of the irrelevance presented by the standard deviation in this case, since it obtained too high values, a fact that can be justified by the use of only 5 samples for the study, as well as the analysis of a single property. Nevertheless, the demonstrated values reflect an information already expected, which consists in the direct proportionality between concrete absorption and replacement content, as seen by Frotté[9].

Nevertheless, the values of the mass difference were submitted to the statistical Student's t-test, in order to check how close, the data are. As a result, it was found that the relative values for the mass differences of each mix ratio are

not statistically different from each other. This conclusion reaffirms the stance described in the previous paragraph, that the best way to analyze these data is to work with their values in an absolute way.

Thus, this effect can be justified by issues previously discussed. These results corroborate, thus, the already expected fact that the recycled aggregates present higher porosity and consequently higher hygroscopy, conferring to the concrete an increase in this analyzed characteristic as well [7].

4.4 Axial compressive strength

The results found for the axial compressive strength of the different mix ratios at ages of 7, 28 and 160 days can be observed in Table 2. The data presented are the averages of the strengths among the 5 specimens tested for each mix at different ages. Table 2 also shows the standard deviations next to each average.

The data were submitted to an entirely randomized statistical design, and the differences were evaluated by Tukey's test at a 5% significance level. It is worth mentioning in the table that the measurements followed by the same capital letter in the column and lower case in the row do not differ by the Tukey test at 5% significance level.

Table 2: Axial compressive strength for the different mix ratios at the three tested ages.

Mix Ratio	7 days		28 days		160 days	
.% of RFA	MPa	Corr.	MPa	Corr.	MPa	Corr.
0	22,75±2,57	Aa	44,61±2,78	Ab	47,32±2,96	Ab
20	19,25±3,52	ABa	33,07±3,35	ABb	37,87±0,84	Bb
40	18,12±2,14	Ba	30,37±1,46	BCb	32,89±3,23	Cb
60	15,95±1,46	Ba	27,69±0,72	Cb	31,0±1,04	Cc

Thus, we can see that at 7 days of curing, there was a slight decrease in strength according to the higher percentage of recycled fine aggregate (RFA), however, the data of the 4 mix ratios are somewhat similar. Analyzing at 28 days, a reduction of that property is again observed, together with a greater distance between the results. However, a greater differentiation at the last age was evidenced, segregating the results into 3 groups, both the mix with 0% and the mix with 20% being individualized, and a greater proximity between those with 40 and 60%. One can see from this that the influence of replacement becomes effective when analyzing the material at an advanced age of curing. This factor can possibly be explained by the higher amount of water incorporated into the mixture due to the presence of recycled aggregates, which depreciates the final strength. Therefore, analyzing Table 2 in rows, in the four categories of concrete was noted the differentiation between the 7 days of curing for the other ages, while at 28 and 160 days, the results remained mostly close. This factor can be understood by the efficiency of the moist curing to ensure the development of concrete strength during the first month. However, it is noteworthy the reduction of the speed of such achievement at ages greater than 28 days. Then, it is possible to observe in Fig. 2 the interpolation of the data obtained by the averages of the strengths, through a logarithmic adjustment, justified by maintaining a better quality of the data correctness. These data were distributed throughout the curing ages and classified according to each concrete mix ratio. Regarding the curves presented in the graph of Fig.3, Table 3 shows the equations for each fitted curve, as well as the coefficient of determination (R^2) of the same.

Table 3: Equations of the fitted curves and R^2 for each mix ratio.

Concentration % de RFA	Regression	R^2
0	$y = 7,5883 * \ln(x) + 12,036$	0,7798
20	$y = 5,8163 * \ln(x) + 9,9936$	0,8898
40	$y = 4,5802 * \ln(x) + 11,318$	0,8267

$$60 \quad \left| \quad y = 4,4069 * \ln(x) + 8,6562 \quad \right. \quad 0,8659$$

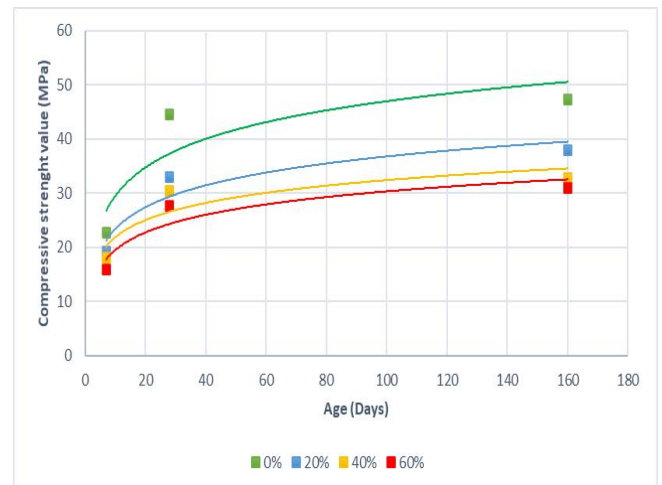


Fig 3: Evolution of the compressive strengths of the mix ratios according to the age. (Author)

Therefore, the variation of the axial compressive strength along the curing age is observed and highlighting the distinction between the curves of each mix, thus evidencing that the compressive strength of concrete is gradually reduced as the recycled fine aggregate (RFA) is incorporated to replace the natural fine aggregate.

In comparison with the baseline concrete at a 28-day curing, a strength loss of 25.85, 31.92, and 37.92% was observed for the mixes with 20, 40, and 60% substitution, respectively. Therefore, a greater reduction of compressive strength is highlighted in the first 20% substitution, and a milder reduction is notified in the following incorporation ranges.

4.5 Tensile strength by diametral compression

Being analyzed at 28 days of curing, the results together with the standard deviations of the four specimens per mix tested for tensile strength by diametral compression can be seen in Table 4.

Table 4: Tensile strength by diametral compression for the different mix ratios.

Concentration	Tensile Strength	
% of RFA	MPa	Correlation
0	3,22±0,355	A
20	2,30±0,703	AB
40	1,86±0,173	B
60	1,80±0,192	B

Therefore, it was noted that the tensile strength decreases as the replacement content of the natural fine aggregate (NFA) by the recycled fine aggregate (RFA) increases, since a reduction of 28.57, 42.24, and 44.10% was observed for mix ratios with 20, 40, and 60% replacement, respectively. It is possible to understand what happened because of the larger amount of water inside the concrete as a consequence of the introduction of recycled aggregate and its pre-wetting. Similarly, such a change in the w/c ratio can be noted in the variations that occurred in the slump test.

When comparing the tensile and compressive strengths, it was verified that the first one corresponds on average to only 6.7% of the total value of the compressive strength.

V. CONCLUSION

The obtaining of the recycled fine aggregate and its incorporation into concrete at different replacement rates propitiated the execution of the tests and analyses explained in this study. With the interpretation and discussion of the results, it was possible to draw conclusions about the effects of the recycled fine aggregates on the characteristics of concrete when incorporated.

The slump and consequently the workability of concrete in its fresh state had an increase from 9.5 to 16 cm, the first measure corresponding to the mixes with 0 and 20% substitution and the second for mixes made with 40 and 60%. This fact promotes the understanding of the effect by distinguishing the particle-size curves of the compared aggregates, as well as the incorporation of water in the pre-wetting.

The absorption of concrete showed growth as higher percentages of the RFA were introduced in the mixture, a factor possibly justified by the higher porosity and absorption by the recycled aggregate when compared to the natural one.

As for the axial compressive strength, a reduction of the property was observed as the percentage of replacement of the natural aggregate by the recycled one increased. There was a more abrupt reduction in strength in the first replacement ranges, and after 20%, the reduction of this property occurred in a milder way. An inverse

proportionality was also observed in the tensile strength obtained by diametral compression, since an equivalence of 6.7% of this property was notified to the value found for the axial compression strength.

Thus, it is possible to state that despite the changes observed in the properties of concrete, the fine aggregate collected has characteristics that allow its incorporation in the material. However, it is emphasized that this use must be made with appropriate caution in order to ensure the control of the influences of the recycled aggregate in the concrete. To do so, pre-use analyses are required so that the present variables in each situation are accounted for and controlled.

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