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INFLUENCE OF TREATMENT OF RECYCLED AGGREGATE ON THE MECHANICAL PERFORMANCE OF CONCRETE BLOCKS

Horácio José Medeiros Silva*[1], João Gabriel Arraes Pinheiro[1], Gabriel Lima Oliveira Martins[2], and Yuri Sotero Bomfim Fraga[2]

[1]Department of Civil Engineering, Centro Universitario Euro-Americano, Brazil
[2]Department of Civil and Environmental Engineering, Universidade de Brasília, Brazil

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***Corresponding author:**
Horácio José Medeiros Silva

ABSTRACT

The environmental pollution and unrestrained consumption of natural resources have become the subject of research. In this context, the construction industry has been contributing, for example, with the reinsertion of construction and demolition waste (CDW) as aggregates in concrete. Thus, this research aimed to verify the influence of the treatment of recycled concrete aggregate (RCA) on the mechanical performance of concrete blocks. For this, concrete blocks with five different compositions were produced, one being a reference with natural aggregates and four replacing 50% and 100% of the natural coarse aggregate by RCA and RCA treated with Portland cement. The water absorption and compressive strength tests were performed. It was observed that the RCA treatment reduced the water absorption and increased the mechanical performance of the concrete blocks. Thus, the treatment of RCA with Portland cement is a viable alternative for the reuse of CDW in civil construction.

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INTRODUCTION

It originated in the 20th century, after the industrial revolution, a series of meetings to discuss environmental preservation and sustainable development, such as the Stockholm conference and ECO-92, for example. Civil construction is fundamental for urban development, but it is responsible for a large generation of construction and demolition waste (CDW). The construction industry demands 20 to 50% of the planet's natural resources (Brasileiro and Matos, 2015). In 2012, with regard to waste generation, more than 35 million tons of CDW were collected from Brazilian municipalities (Nagalli, 2016).
There is an exponential population growth after the technological advances of the 21st century. This demographic increase demands, more and more, the consumption of materials and the degradation of the environment. It is up to civil construction to meet the population's needs in relation to mobility, housing and infrastructure in general. Concrete is a material used in constructions, consisting of a hydraulic binder, usually Portland cement, fine aggregate, coarse aggregate, water, additives and/or additions. According to Mehta and Monteiro (2014), concrete is the second most used material in the world. From the context, innovations in civil construction to make it more sustainable are necessary. As concrete is one of the main materials used in engineering, recycling it or using recycled materials in its production is an alternative for reducing environmental impacts. According to Buttler (2007), for example, the Dutch government raised taxes related to the improper disposal of solid waste by 500%, reaching levels above 80% of recycling. Silva (2019) points out the reuse of CDWs as a potential source of aggregates for concrete, called recycled concrete aggregates (RCAs) and mixed recycled aggregates (MRAs). It was shown that the use of recycled aggregates increases the demand for water due to the greater absorption capacity of recycled aggregates due to its greater porosity in relation to natural aggregate. By pre-treating the aggregate with Portland cement, there is a reduction in the porosity of the recycled aggregate and an improvement in the transition zone, resulting in concrete with greater durability and greater mechanical performance.

Currently, there is a large number of studies on the use of recycled aggregates, with or without treatment, in concrete (Adesina and Das, 2021; Bai et al., 2020; Wang et al., 2021; Zeng et al., 2020). Despite this, few studies are intended to investigate the application of recycled aggregates in concrete blocks (Guo et al., 2018; Liu et al., 2019; Chu et al., 2021). Given the above, aiming to fill the gap found in the literature, this research aims to evaluate the influence of pretreatment with Portland cement of recycled concrete aggregates for use in concrete blocks, in order to verify the water absorption and mechanical performance.

LITERATURE REVIEW

Current overview: Civil construction is always correlated with the country's economy and development, in addition to being essential for societies based on the capitalist economic system, this sector represents the human activity that consumes the most natural resources on the planet, in the order of 20 to 50% (Brasileiro and Matos, 2015). The main inputs demanded are rocky inert materials, finite products that are exploited on a large scale today. In Brazilian cities, construction and demolition waste represent between 41 and 70% of the total production of urban solid waste (Nanya, 2018). The urban development of Brazilian cities has given rise to an increase in the generation of waste from the construction industry which, together with the lack of management, results in several urban problems. It is noteworthy that it was only in 2002 that the first public policy initiative for waste management was created through Resolution No. 307 of the National Council for the Environment (CONAMA, 2002). According to Pinheiro (2007), the most widespread material in civil construction is concrete, as it can be molded according to the project's needs and has high compressive strength. Among the materials that make up concrete, the aggregates represent about 70% of the final volume of the mix, increasing the stability of the mixture and reducing the consumption of cement, a more expensive input. Aggregates used in civil construction are acquired through mineral extraction, consuming natural resources. In this context, recycling presents itself as a viable solution for reducing the environmental impact of the construction industry. In 2010, the Brazilian Law No. 12,305, National Policy on Solid Waste, was approved, which defined the waste disposal processes, encouraging companies that generate waste to adopt recycling processes in their production chain, aiming at the gradual implementation of the concept of sustainability. This concept has been implemented in several developed countries. In Germany, for example, there is the Waste and Whole Cycle Economy Act of 1994, with recommendations for the use of recyclable and recycled materials.

Aggregate properties: According to NBR 15113 (ABNT, 2004), CWDs are residues originating from repairs, constructions and demolitions, as well as those originating from preliminary activities. Recyclable CDWs used as aggregates in civil construction have physical and mechanical characteristics that enable their reintroduction in the construction industry. Due to the nature of the acquisition of these materials, they present variations in their composition, being sub-classified, according to NBR 15116 (ABNT, 2004), in recycled concrete aggregate (RCA) and mixed recycled aggregate (MRA) based on the percentage of cement Portland, RCA has at least 90% of its mass based on Portland cement, compared to MRA, which has less than 90% of its mass based on Portland cement. Recycled concrete aggregates, as they are cementitious, have a higher porosity than natural aggregates. Thus, the greater the porosity of the aggregate, the lower its specific mass, as shown in table 1. According to Nanya (2018) and Pandurangan et al. (2016), the specific mass of the aggregate directly influences the properties of concrete in the fresh and hardened states.

Table 1. Specific mass of natural and recycled aggregates

Author	Specific mass (kg/m³)	
	Natural aggregate	RCA
Pandurangan et. al. (2016)	2.70	2.45
Nanya (2018)	2.82	2.72

The aforementioned porosity as well as the hygroscopic nature of the materials that make up the RCAs corroborate the amplification in the water absorption (%) of the recycled aggregates. According to the studies developed by Nanya (2018) and Dimitriou et. al (2018), there is a considerable increase in this property, as shown in table 2.

As mentioned above, recycled aggregates have inferior characteristics compared to natural aggregates, and a pre-treatment of aggregates is recommended to improve their properties. For Purushothaman et al. (2015), the uniform application of binders, such as cement, for example, on the surface of the aggregate results in an increase in its density, that is, there is a reduction in porosity and less water absorption. The effect of this pre-treatment is observed in the increase of the compressive strength of concrete with treated CWD's.

Table 2. Absorption of water from natural and recycled aggregates

Author	Water absorption (%)	
	Coarse natural aggregate	RCA
Dimitriou et al. (2018)	2.50	7.20
Nanya (2018)	0.30	5.85

According to Tavares and Kazmierczak (2016), it was found, based on the aforementioned properties of recycled aggregates, that the properties of concrete in the fresh state, such as consistency and workability, and the mechanical strength, observed in the hardened state, present loss of performance compared to concretes dosed using natural aggregates. These characteristics were obtained using a percentage variation of replacing the natural aggregate with the recycled one in the order of 30%, 50%, 70% and 100%, with a water/cement ratio equivalent to 0.59, 0.62, 0.65 and 0 .70, respectively, with the slump test, regulated by NBR NM 67 (ABNT, 1998), set at 100±10 mm. The concrete transition zone is represented by the region between the aggregate and the cement paste. This is a region of concrete fragility due to the accumulation of $Ca(OH)_2$ on the surface of the aggregate. When it comes to RCAs, this region is even more compromised, considering that there is the formation of two transition zones, one coming from the recycled aggregate itself and the other formed between the recycled aggregate and the new cement paste, as it can be observed in figure 1.

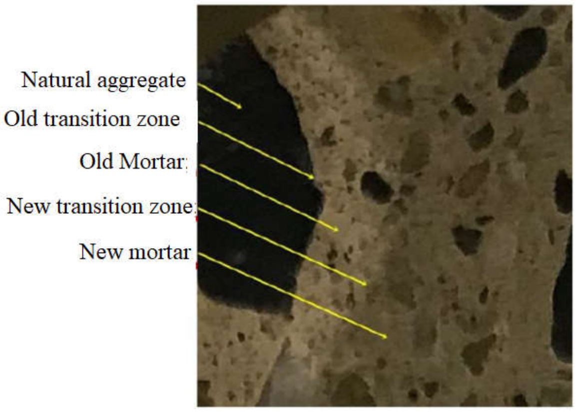

Figure 1. Interface between the cement matrix and the recycled aggregate (SILVA, 2019)

Concrete blocks: Currently, there are specific researches that aim to reach the minimum technical requirements of mechanical, physical and durability properties, providing the reuse of recycled aggregates in new concrete dosages. According to Silva (2019), due to the composition of the CDWs, it is essential to carry out treatments on the aggregate, since it has a high porosity and water absorption content. It is noteworthy that the concrete used in the manufacture of blocks must have a drier aspect to enable the demolding process immediately after the process of filling the form and compacting. The NBR 6136 standard (ABNT, 2016) defines as simple concrete block, blocks produced with concrete, with cavities in their upper and lower faces, which can be used for structural purposes or not for the execution of masonry. To enable the use of RCAs, fine or coarse, in concrete blocks, the normative prerequisites prescribed in NBR 7211 (ABNT, 2009) must be met. According to NBR 6136 (ABNT, 2016), the characteristic to axial compressive strength in structural or sealing concrete blocks must result, at 28 days, values higher than or equal to 4 MPa and higher than or equal to 3 MPa, respectively. In order for the design parameters to be achieved and to maintain the quality of the works, these normative requirements must be met.

MATERIALS AND METHODS

Materials: To carry out the research, Portland cement CP V-ARI, natural fine aggregate, natural coarse aggregate, mixed recycled coarse aggregateand polycarboxylate-based superplasticizer additive were used. The characteristics of the materials are shown in Table 3.

Table 3. Properties of materials

Material	Properties		Value
CP V - ARI	Specific mass (g/cm³)		3.15
	Fineness index on the 75 µm sieve (%)		2.00
	Set times	Start (min)	115
		End (min)	204
Natural fine aggregate	Maximum characteristic dimension (mm)		4.75
	Fineness module		3.34
	Specific mass (g/cm³)		2.65
Natural coarse aggregate	Maximum characteristic dimension (mm)		12.5
	Fineness module		5.85
	Specific mass (g/cm³)		2.38
Recycled coarse aggregate	Maximum characteristic dimension (mm)		12.5
	Fineness module		6.02
	Specific mass (g/cm³)		2.62

Figure 2 shows the granulometric curves of the fine and coarse aggregates.

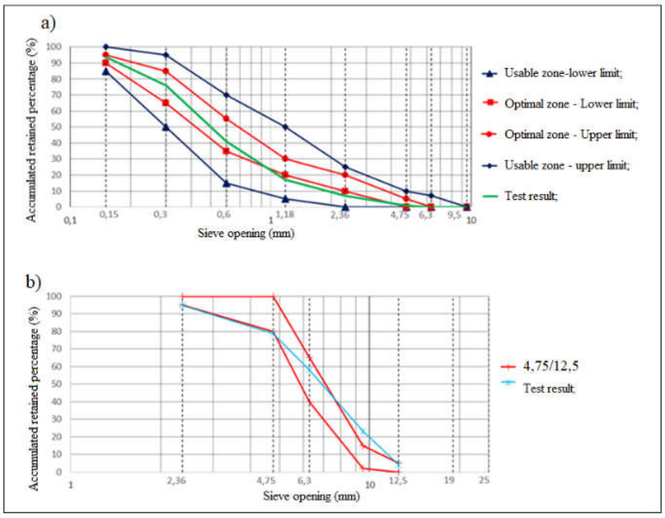

Figure 2. Particle size curve of (a) fine aggregate; (b) coarse aggregate

As can be seen in Figure 2(a), the fine aggregate used in this research meets the limits of the usable zone in concrete of NBR 7211 (ABNT, 2009), and it can be observed that the fine aggregate is found almost entirely within the optimal zone. As shown in Figure 2(b), the coarse aggregate is in the range 4.75mm/12.5mm (smaller/larger dimension) according to NBR 7211 (ABNT, 2009). The origin of the CWDs used comes from constructions and demolitions that took place in the Federal District. In order to adapt to its reuse, the manual crushing process was chosen, aiming to obtain a volume of waste belonging to the granulometric range corresponding to 0 gravel, diameter ranging between 4.8 mm and 9.5 mm, according to ABNT NM 248 (2003).

Production and curing of concrete blocks: Five different concretes were produced for the production of the blocks, one being a reference using 100% natural aggregate, two substituting 50% and 100% of natural aggregate with recycled aggregate and two substituting 50% and 100% of natural aggregate with recycled aggregate treated with Portland cement. The nomenclature of the studied blocks is shown in Table 4.

Table 4. Classification of the produced blocks

BLOCK	COMPOSITION
REF	Concrete with 100% natural coarse aggregate.
50NA50 RA	Concrete with 50% natural coarse aggregate and 50% recycled coarse aggregate.
50NA50T RA	Concrete with 50% natural coarse aggregate and 50% treated recycled coarse aggregate.
100RA	Concrete with 100% recycled coarse aggregate.
100TRA	Concrete with 100% treated recycled coarse aggregate.

After obtaining the recycled aggregates and characterization of the components, the 1:4:4 mix was adopted (cement:fine aggregate:coarse aggregate) and w/c ratio equivalent to 0.5, based on the usual methodology applied in production concrete block industry, for example at the company Lajes São Francisco in Santa Maria/DF, Brazil. From the reference mix, the replacement, in volume, of natural aggregate by recycled aggregate (with or without treatment) was carried out. The treatment of aggregates with cement consisted of immersing RCA's in a cement paste, where they were uniformly immersed and stirred for a period of 20 minutes, methodology adapted from Tam and Tam (2008), Zhihui et al. (2013) and Güneyisi et al. (2014). Drying in natural air was used, in order to reduce aggregate pores and water absorption, increase density and provide better interfacial adhesion between the aggregate and the mortar of the new concrete. The concrete blocks were produced and compacted manually using a concrete block form with dimensions of 9 x 19 x 39 cm (width x height x length), as shown in Figure 3.

Figure 3. Form for production of concrete blocks

Tests were carried out to verify the water absorption and compressive strength of the blocks produced, according to the requirements of NBR 6136 (ABNT, 2016). For the water absorption test, the capillary water absorption test was used. The blocks were placed in a closed container with two steel bars at the base of each block to prevent the bottom face from being fully supported on the bottom, with the water level being equal to 0.5 cm at the bottom of the block. A digital scale was used to obtain the blocks' weight. The water absorption test is related to the block's porosity with the capacity to retain liquid in its interior. Thus, the amount of water that is absorbed by the specimen was verified in percentage values. To determine the compressive strength, three blocks per mix were used, which were broken after 7 days of hydration in a manual hydraulic press to obtain the breaking load. To regularize the samples, two 3mm thick neoprene sheets were used. In this test, the load capacity that the specimen supports, when subjected to a force exerted perpendicular to its faces, is verified. The compressive strength results were treated and analyzed using the Statistica v.10 software. An analysis of variance (ANOVA) was performed, in which it was verified whether there was a significant difference in the properties of the blocks analyzed considering a significance level of 0.05.

This significant difference is evaluated through the probability of significance (p-value), in which, for significant results, the p-value must not be higher than the significance level. If the p-value is equal to or higher than the significance level, the compressive strengths are considered statistically equal. Subsequently, Duncan's test was performed to group the different concrete blocks into homogeneous and heterogeneous strength classes with a 95% confidence interval.

RESULTS

Water absorption: The absorption test aimed to evaluate the concrete blocks for capillary absorption, described in the NBR9779 standard (ABNT, 2012). Three blocks of each mix were submitted to the test, with weighing at 3, 6 and 24 hours. Table 5 presents the mean mass values for each mix. Based on the results shown in Table 5, the percentage increase in mean mass of the 3 specimens of 100RA is equivalent to 1.09% after 24 hours. Similarly, the average for the specimens of 100TRA resulted in 0.59%, demonstrating a significant reduction in water absorption of the treated aggregate compared to the untreated one.

presenting lower absorption rate. According to standard NBR 6136 (ABNT, 2016), blocks are classified into three classes (A, B and C) according to their characteristic compressive strength and water absorption rate. For class A blocks, the water absorption is up to 8%, therefore all tested blocks are meeting the established absorption limit. The results of this research corroborate Buttler (2007), who observed that the water absorption rate of the 100% composed block by natural coarse aggregate is lower when compared to taits that present natural aggregate (NA) by recycled aggregate (RA) substitution contents, which was also observed in this research. Furthermore, after the three weighings (3h, 6h and 24h), in all cases the treatment provided less water absorption, which demonstrates that the treatment improved the aggregate surface, according to the analysis by Silva (2019).

Compressive strength: In the compressive strength test, the maximum force to which each block was submitted was obtained, in tons-force (tf), before breaking. To analyze the supported stress, the dimensions of each block were considered in order to determine the area of action of the axial strength. The average results of the compressive strength test of the five groups of molded blocks are shown in Figure 4.

Table 5. Results of the capillary rise water absorption test

Sample	Volume (cm³)	Dry weight (g)	Sat. weight 3h (g)	%	Sat. weight 6h (g)	%	Sat. weight 24h (g)	%
REF	4161.00	8844.55	8873.73	0.33	8880.81	0.41	8893.19	0.55
50NA50RA	4161.00	8279.40	8511.63	0.93	8527.91	1.13	8567.17	1.60
50NA50TRA	4161.00	8432.03	8322.47	0.52	8327.93	0.59	8341.06	0.74
100RA	4161.00	8381.40	8440.30	0.69	8448.43	0.79	8473.94	1.09
100TRA	4161.00	8090.10	8122.97	0.41	8127.23	0.46	8137.36	0.59

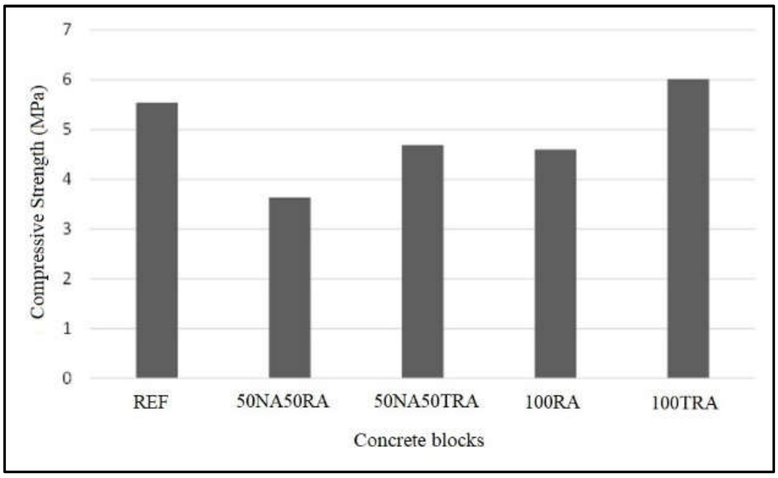

Figure 4. Mean values of compressive strength at 7 days of hydration

Table 6. Analysis of variance (one-way ANOVA) of axial compressive strength of concrete block at 7 days of manufacture

Age	SQ	MQ	F	p-value	Result
7 days	10.18	2.55	16.18	0.000229	significant

SQ= Sum of squares;
MQ= Mean squares;
F= Fisher parameter for the significance test;
p-value= probability of significance.

Table 7. Duncan test results for compressive strength of concrete block at 7 days of hydration

Age	Samples	Average compression strength (MPa)	Standard deviation (MPa)	Group 1	Group 2	Group 3
7 days	REF	5.54	0.6			X
	50NA50RA	3.63	0.2	X		
	50NA50TRA	4.69	0.4		X	
	100RA	4.60	0.3		X	
	100TRA	6.01	0.6			X

It is verified that there is the same absorption difference for the mixtures with substitution contents corresponding to 50% (50NA50RA and 50NA50TRA) with the treated aggregates

In general, it was observed that the 100TRA block, composed entirely of coarse treated aggregates, presented compressive strength slightly higher than the other groups in which only natural aggregates and untreated recycled treats were used. Treatment on the RCA provided, on average, a 30% increase in the compressive strength of the blocks 50NA50TRA and 100TRA in relation to the blocks with RCA without treatment (50NA50RA and 100RA, respectively). The results of the analysis of variance (one-way ANOVA), shown in table 6, showed that the p-value was less then the significance level of 0.05 at 7 days of hydration. As can be seen in the table 7, according to Duncan's test, the compositions were divided into three groups, considering the mean and standard deviation of the compressive strength. Group 1 is composed of the 50NA50RA block, which presented the lowest compressive strength. In group 2, blocks 50NA50TRA and 100RA were included, being considered of intermediate compressive strength. Group 3, with higher compressive strength, is composed of REF and 100TRA blocks, that is, the block in which the treatment was used managed to exceed the blocks without the treatment in all tests performed. Thus, it was shown that when comparing blocks with 50% recycled aggregate, the treatment was significantly effective in increasing mechanical performance, given that the 50NA50RA block was classified in group 1 and the 50NA50TRA block was classified in group 2. This same result was observed with the replacement of 100% of natural aggregate by recycled aggregate, in which the 100RA block was classified in group 2 and the 100TRA block was classified in group 3, confirming the significant influence of the treatment of the aggregate in the increase of compressive strength. It should be noted that it is possible to replace 100% of natural aggregates with recycled aggregates without compromising mechanical performance, as long as the treatment is carried out, as shown in Table 7. Group 1 is composed of the 50NA50RA block, which presented the lowest compressive strength. In group 2, blocks 50NA50TRA and 100RA were included, being considered of intermediate compressive strength.

Group 3, with higher compressive strength, is composed of REF and 100TRA blocks, that is, the block in which the treatment was used managed to exceed the blocks without the treatment in all tests performed. Thus, it was shown that when comparing blocks with 50% recycled aggregate, the treatment was significantly effective in increasing mechanical performance, given that the 50NA50RA block was classified in group 1 and the 50NA50TRA block was classified in group 2. This same result was observed with the replacement of 100% of natural aggregate by recycled aggregate, in which the 100RA block was classified in group 2 and the 100TRA block was classified in group 3, confirming the significant influence of the treatment of the aggregate in the increase of compressive strength. It should be noted that it is possible to replace 100% of natural aggregates with recycled aggregates without compromising mechanical performance, as long as the treatment is carried out, as shown in Table 7. These results corroborate the literature, considering that similar treatments resulted in an increase in the mechanical performance of concretes containing treated recycled aggregate compared to concretes with untreated recycled aggregate due to the surface improvement of the aggregate (Tam and Tam, 2008; Zhihui et al., 2013; Güneyisi et al., 2014). This improvement can be evidenced in this research through the water absorption test by capillary rise shown in Table 5, in which the treatment of the aggregates provided a reduction in the water absorption of the blocks.

CONCLUSION

Through this research, it was possible to observe that the treatment of recycled concrete aggregate by immersing the aggregate in a Portland cement paste enables the reduction of water absorption and the increase of the compressive strength of concrete blocks compared to blocks with recycledaggregateuntreated. Furthermore, it is possible to replace up to 100% of the natural aggregate with recycled concrete aggregate without reducing the mechanical performance through this treatment. Thus, the results achieved by the research contribute to the literature, considering that it is possible to minimize the environmental impacts with the extraction of natural aggregates and the disposal of construction and demolition waste. Furthermore, it has been proven that the production of concrete blocks with recycled aggregates is an environmentally and technically viable alternative, performed in a simple and effective way, using only basic elements existing, without the need for more specific or sophisticated equipment.

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