

# REVISTA AIDIS

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Investigación, desarrollo y práctica.

## RECYCLING OF CONSTRUCTION AND DEMOLITION WASTE AS AGGREGATE FOR PAVEMENT BLOCK PRODUCTION

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## RECICLAGEM DE RESÍDUOS SÓLIDOS DA CONSTRUÇÃO CIVIL COMO AGREGADO PARA PRODUÇÃO DE BLOCO PARA PAVIMENTAÇÃO

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### Abstract

*The objective of this paper is to evaluate the performance of recycled concrete aggregate for use in the production of pavement blocks. For this research project, aggregates were obtained from various sources of recycled waste, including wall plaster, ceramic tiles and concrete flooring. The concrete mixtures were prepared using three different quantities of recycled aggregate: 25%, 50% and 100% of the total aggregate weight. The structural properties of the concrete mixtures were analyzed using slump cone measurements and compressive strength tests (cube tests) at 3, 7 and 28 days. The results obtained indicated that the compressive strength of all mixtures increased with time. However, it was also noted that the compressive strength of the concrete mixtures decreased as the quantity of recycled aggregate increased. The maximum compressive strength was achieved at 28 days by the concrete mixture comprised of 25% recycled aggregate, which was obtained from concrete floor waste. This illustrates that the use of this type of recycled aggregate allows engineers to obtain concrete mix designs which meet the structural requirements for application in pavement blocks.*

**Keywords:** construction waste, demolition waste, recycled aggregate, pavement block, concrete.

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## Resumo

O objetivo deste trabalho é avaliar o comportamento do agregado reciclado de concreto para a confecção de blocos para pavimentação. Para este artigo, os agregados foram obtidos de diversas fontes de resíduos reciclados, incluindo revestimento de paredes, piso cerâmico e concreto de piso. Os traços de concreto foram preparados usando três proporções de agregado: 25%, 50% e 100% da massa total de agregado. As propriedades estruturais dos traços de concreto utilizados foram analisadas através de ensaios de abatimento de tronco de cone e de resistência à compressão axial simples aos 3, 7 e 28 dias. Os resultados indicaram que a resistência à compressão de todos os traços aumentou ao longo do tempo. No entanto, percebeu-se também que a resistência à compressão dos traços diminuiu à medida que a quantidade de agregado reciclado aumentou. A máxima resistência à compressão axial simples do concreto foi alcançada aos 28 dias pelo traço com 25% em massa de agregado reciclado, obtido pelo resíduo de concreto de piso. Isto ilustra que o uso deste tipo de agregado reciclado possibilita aos engenheiros dosar misturas de concreto que atendam aos requisitos estruturais para a aplicação como blocos de pavimentação.

**Palavras chave:** resíduo de construção, resíduo de demolição, agregado reciclado, bloco de pavimentação, concreto.

## Introdução

According to the International Council for Building (CIB), the construction industry is a major contributor to socioeconomic development in all countries (Brasil, 2014). However, CIB points to the construction industry as the sector that consumes the most natural resources and non-renewable energy, generating significant long-term environmental impacts. In addition to the impacts of energy consumption, there are also those related to the generation of solid, liquid and gaseous waste. According to the Brazilian Association for Recycling of Construction and Demolition Waste - ABRECON, about 60% of the solid waste generated by all human activities come from the construction industry, 70% of which could be sourced from recycled materials (Miranda et al., 2016).

The civil construction industry is directly responsible for a great number of environmental impacts. Frequently, it is the source of a significant amount of hazardous waste, which is often improperly disposed of in wastelands and public areas, as shown in Figures 1 and 2.

The improper disposal of residues causes serious problems to the urban environmental management, including premature breakdown of areas for final waste disposal, blockage of urban drainage elements, degradation of water fountainheads, accumulation of dirt on the roads and the proliferation of insects and rodents, requiring repair works at great expense to public funds (Ribeiro, 2004). The impacts of embankments constructed with debris can also be considered, which can bring about contamination of the underlying soil and underground water sources.

Considering this evidence, recycling emerges as an important practice to promote as it reduces problems related to the waste disposal in urban areas. In this case, recycled materials (ceramics, bricks, concrete, floors, tile boards, among others) can be used for several purposes, including as

aggregates that can be applied to several cases, such as base and sub-base of pavements, production of concrete breeze-blocks, paving blocks and drainage tubes as well as various landscaping applications.

Thus, taking into account the importance of a recycling process for the environment, this paper aims to evaluate the performance of concrete masses made using recycled aggregates for the production of pavement blocks. Different studies were undertaken investigating the behavior of concrete masses made with recycled aggregates from a range of waste sources, including walls, ceramic tiles and cement-based concrete flooring.



**Figure 1.** Disposal of construction and demolition waste: in sidewalks (left) and in wastelands (right) in Boa Vista, Roraima, Brazil.



**Figure 2.** Disposal of construction and demolition waste on the Capibaribe River margins, in Recife-PE, Brazil.

### Concrete using aggregates from civil construction residue

Concretes produced with recycled aggregates usually have different characteristics from those produced using conventional aggregates, which depends on the type and quality of the aggregates. Changes in the concrete performance related to water-cement ratio, consumption of binders, variability in the composition, physical and chemical characteristics of the aggregates, as well as various other properties have been checked. However, it is possible to obtain concretes with desired properties for a great variety of construction services, although it is important to be careful with the aggregate choice, with the residues selection and classification, as well as ensuring thorough removal of existing contaminants, among other factors (Lovato, 2007).

The main property evaluated in relation to the influence of the recycled aggregate in fresh concrete, is its workability. This is one of the main properties which is most affected by the use of recycled aggregates, due to the often irregular shape, the rougher texture, and the higher water absorption rate. As a result of these factors, the use of recycled aggregates leads to a decrease in the workability of the *in-situ* concrete. To compensate this, it is necessary to increase the amount of water in the mixture, which in turn may influence the properties of the hardened concrete (Lovato, 2007).

Hansen (1992) found that concretes produced with recycled coarse aggregates needed 5% more water than the conventional concrete to achieve the same workability. This increase of water content can reach 15% when coarse and fine recycled aggregate are used.

Leite (2001), evaluated the workability of concrete containing recycled aggregates in different percentages. The author noted that concretes containing only recycled fine aggregates showed the highest slump values and that after the addition of recycled coarse aggregate in the mix, the slump tended to decrease. The author also discovered that the fine content in the concretes with low water-cement ratio, contribute to the greater slumps obtained in mixtures containing recycled fine aggregate.

Among the structural properties of concrete, the most studied is the compressive strength. According to Banthia and Chan (2000) the difference between the strength of conventional concrete and concrete with recycled aggregates depends, among other factors, on the replacement content of aggregates, the characteristics of the original concrete, the nature and percentage of contaminants, and the amount of fines and mortar adhered to in the recycled aggregates.

According to Rahal (2007), concretes with 100% of recycled coarse aggregate showed a decrease of 9% on its compressive strength when compared to similar concrete made with conventional aggregate.

According to Dhir et al. (1999), no decrease in the concretes compressive strength was noted in the mixtures produced with up to 20% of recycled fine aggregate, or 30% of recycled coarse aggregate. When the percentage of recycled aggregates was higher than these values, a substantial decrease on the compressive strength was observed in the concrete produced.

Leite (2001) has also found out that the compressive strength of concretes is greatly influenced by the porosity of the materials in the mixture, as well as the porosity of the transition zone. When using recycled aggregate, the water-cement ratio and the content of recycled coarse aggregate are the primary factors that greatly influence the compressive strength of the produced concretes.

Lima (1999) and Leite (2001) claim that, due to the possibility of pozzolanic reactions in the recycled aggregates, they can contribute to the improvement of the compressive strength of concretes, especially in older concrete samples. These authors state that the use of the recycled aggregate without the presence of natural aggregate produces greater strength rates at 28 and 91 days, indicating that pozzolanic activity brings about greater strength in recycled aggregate.

### Materials and methods

This research experiment utilized various testing methods through the use of the following test: qualitative characterization of waste; physical characterization of the CDW (Construction and Demolition Waste) recycled aggregates; slump test, and compression tests in order to come up with a mixture made up mainly of recycled aggregate, water, and cement that would satisfy the requirements of the standards for pavement block production.

For this research project, were studied three types of recycled waste: ceramic tiles, wall plaster and concrete flooring, as shown in Figures 3.



**Figure 3.** Recycled aggregate: ceramic CDW (left), plaster CDW(center), and concrete CDW (right).

A flow chart is shown to fully illustrate the activities covered in this research. The following are the step-by-step procedures used in the design of the concrete mix show in Figure 4 (see below).

As shown in Figure 4, this research was divided in four stages: the first stage consisted of waste collection; the second stage consisted of qualitative characterization and crushing; the third stage was performed physical characterization of aggregates and definition of the studied concrete mixtures and for the fourth stage a slump test was carried out on fresh concrete, for four kinds of concrete mixes, which subsequently underwent compression testing at 3, 7, and 28 days when cured. In this work, 30 (thirty) cylindrical specimens of 30 cm height and 15 cm diameter were molded.

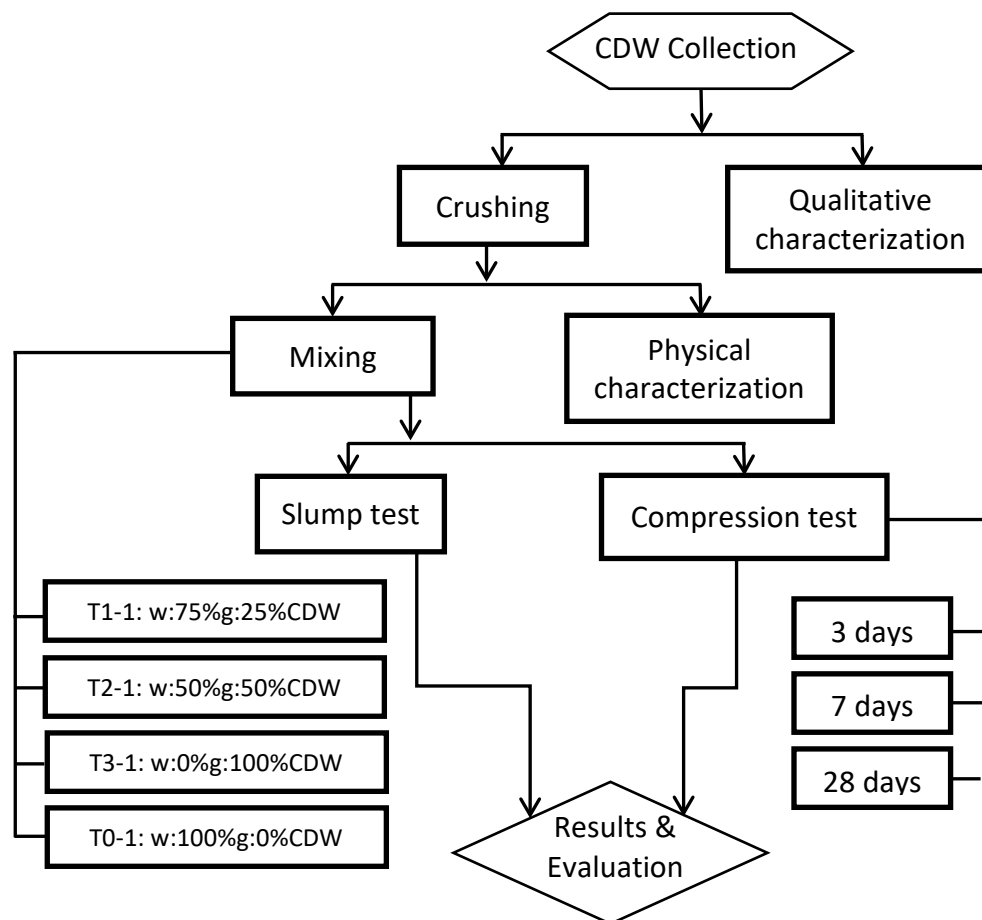


Figure 4. Research flowchart.

### Waste collection

The construction and demolition waste (CDW) used in this study was collected from two houses, which have gone through renovation and expansion works and have had part of their structures demolished. The waste was transported from the construction sites to the Soil Mechanics and Construction Materials Laboratory of the Federal University of Roraima. The volume of waste in loose state was approximately 5 m<sup>3</sup> (Figure 5).



**Figure 5.** Collection and disposal of CDW.

This analysis was performed to determine the nature of the constituent materials in the residue (CDW), by determining their gravimetric composition. The gravimetric composition analysis of the waste is one of the most important issues to be considered in the studies of recycled materials.

The waste undergone a crushing process, in order to obtain an appropriate aggregate size for its required use. Initially, the waste was subjected to a manual fragmentation, to reduce larger particles and then it was put into a small crusher, as shown in Figure 6.



**Figure 6.** Crushing process: hand-driven crushing (left) and mechanic crusher (right).

After the crushing process was completed, the aggregates were subjected to some characterization tests to obtain the following physical properties: grain size, bulk specific gravity, apparent specific gravity, water absorption, and Los Angeles abrasion.

In order to determine the grain size distribution of the recycled aggregates, the Brazilian standard named as NBR NM 248 (ABNT, 2003b) was used.

The specific gravity of an aggregate is defined as the ratio of the mass of solid in a given volume of sample to the mass an equal volume of water at the same temperature. The specific gravity is cluster under three different conditions; namely bulk, apparent and saturated specific gravity. The bulk specific gravity is where the specific gravity of the aggregate is determined under the natural environment and the apparent specific gravity is determined after the aggregate is oven dried for 24 hours (Rahman and Hamdam, 2009). These tests were obtained using the procedures described in the following Brazilian Standards NBR NM53 (ABNT, 2003a).

This test quantifies the quality score of the aggregate, i.e., the ability to be modified when handled. It is obtained according to the procedures recommended by the Brazilian standard NBR NM51 (ABNT, 2001).

The molding and preparation of test specimens began with the definition of the studied concrete mixtures. Three different kinds of mixtures were obtained, replacing the natural coarse aggregate with recycled coarse aggregate at 25%, 50% and 100% of total aggregate weight. The mixtures nomination and their constituent ratios are: T1 – 1:w:75%g:25%CDW (concrete with 25% of recycled coarse aggregate); T2 – 1:w:50%g:50%CDW (concrete with 50% of recycled coarse aggregate); and T3 – 1:w:0%g:100%CDW (concrete with 100% of recycled coarse aggregate); where: w = medium sand, g = natural coarse aggregate, and CDW = coarse aggregate from construction waste.

In addition, the authors referenced a mixture for comparative purposes – T0 – 1:w:100%g:0%CDW (conventional concrete, with natural, coarse basaltic aggregate).

The design of the mixtures was made according to methodology proposed by the Brazilian Portland Cement Association (ABCP), by setting a water-cement ratio (w/c) of 0.4, aiming to achieve a  $f_{ck28} \geq 35\text{MPa}$ , which is the strength recommended by the Brazilian standard NBR 9781 (ABNT, 2013). The cement used into mixtures was the CP II F-32.

The concrete workability was determined using the results of Slump Tests (Figure 7), according to the Brazilian standard NBR NM 67 (ABNT, 1998).





Figure 7. Slump tests.

The curing process was performed by immersing all specimens in water for a period of 3, 7 and 28 days. Figure 8 illustrates the molding, curing, demolding and capping processes of the specimens. The capping stage consisted of the regularization of the specimen bases with a bonded capping polymer, preparing them for the further axial compressive test.



Figure 8. Preparation of the specimen (from left to right): fresh concrete, molding, curing, and striking.

In order to check the compressive strength, the concrete specimens produced with recycled aggregates and natural aggregates were subjected to compressive strength tests, after 3, 7 and 28 days under curing, according to the Brazilian standard NBR 5739 (ABNT, 2007).

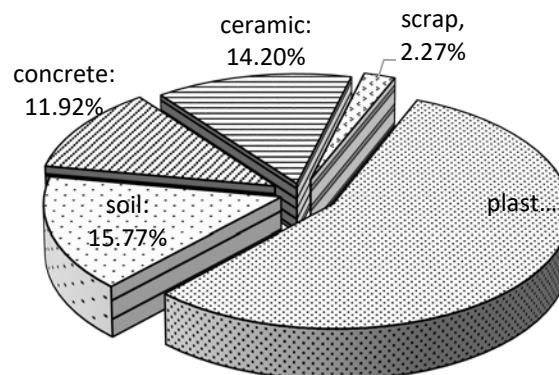
The Figure 9 shows a compressive strength test being carried out on the studied specimens. The compressive strength ( $f_c$ ) is expressed as  $f_c = W_f / A_p$ , where: “ $W_f$ ” is the maximum load value applied on each specimen in kN, and “ $A_p$ ” is the cross section area of the specimen in  $m^2$ .



**Figure 9.** Compressive strength test on concrete.

### Results and discussion

Figure 10 shows the gravimetric composition of the waste (CDW) samples used in this study. It can be observed that there is a predominance of the samples with plaster (55.84%), followed by those with soil (15.77%), but ceramic materials from tiles and bricks (14.20%), concrete from demolition of sidewalks and other structural elements (11.92%), and scrap (2.27%) are also present in the studied waste sample composition.



**Figure 10.** Waste gravimetric composition (CDW).

Figure 11 shows the grain size distribution curve obtained. According to these results the recycled aggregates can be classified as Gravel #8 ( $4.8 \text{ mm} < D_{eq} < 12.5 \text{ mm}$ ). The fineness modules calculated for the recycled aggregates were 2.88 for plaster CDW, 2.64 for ceramic CDW and 2.38 for concrete CDW.

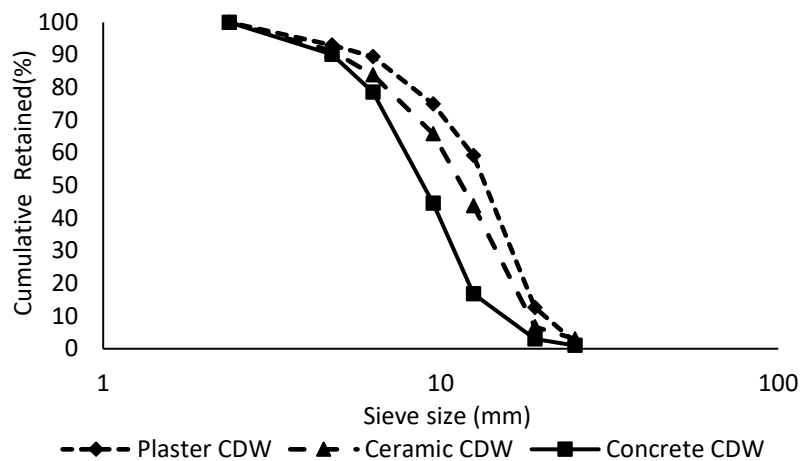


Figure 11. Waste gravimetric composition (CDW).

The acknowledgment of the grain size distribution of the aggregates is important for the mixture design process, as this influences the cement-water content used in the mixtures and consequently both the strength and workability of the mixture.

Table 1 shows the apparent specific gravity, bulk gravity and water absorption values for the tested materials. As can be observed, the bulk gravity and apparent specific gravity values of the recycled aggregates were similar to those obtained in the other studies (Maselev et al., 2008; Padmini et al., 2009; Brito et al., 2005; Rilem, 1994). However, the density of the recycled aggregate is lower than that of natural aggregate.

Table 1. Physical properties of used aggregates.

Parameters	Ceramic CDW	Plaster CDW	Concrete CDW	Basaltic Gravel
Apparent specific gravity ( $\text{g}\cdot\text{cm}^{-3}$ )	2.41	2.66	2.70	-
Bulk gravity ( $\text{g}\cdot\text{cm}^{-3}$ )	1.69	1.88	2.03	2.50
Absorption (%)	20.04	12.64	11.40	1.30

Nota:

Lower specific gravity aggregate increases its absorption capacity and subsequently reduces its strength. Therefore, a greater amount of water and cement is required, and this makes it difficult to achieve the required levels of concrete strength and durability (Morales et al., 2011). Several recommendations give limits for this parameter.

Rilem's recommendations (Rilem, 1994), which provide specifications for concrete made from recycled aggregates. According to these recommendations, aggregates should have a minimum specific gravity of  $1.5 \text{ g.cm}^{-3}$ .

As can be observed, ceramic aggregates had higher absorption than the other investigated materials. Recycled aggregate is more absorptive than natural aggregate. Due to its high absorption capacity, recycled coarse aggregate must be wet before use. If the recycled coarse aggregate is not humid, it absorbs water from the paste, thus losing both its workability in the fresh concrete, as well as the control of the effective w/c ratio in the paste (Morales et al., 2011; Etxeberria et al., 2007).

Therefore, according to these authors, the increased absorption of recycled aggregate means that concrete made with recycled coarse aggregate and natural sand typically needs 5% more water than conventional concrete in order to obtain the same workability. Furthermore, the Rilem guidelines (Rilem, 1994) specified a water absorption limit lower than 10%. The results of the present study reveal that compared with these guidelines, the natural aggregate has complied, whereas natural aggregate did not.

Table 2 shows the results on the Los Angeles abrasion tests, for the recycled aggregates (CDW) and the natural aggregate, which was taken as a reference. The results show that the recycled aggregates (CDW) had loss due to abrasion higher than the natural aggregate. According to the Brazilian standard NBR 7211 (ABNT, 2005), the recycled plaster and ceramic aggregates tested cannot be used to make concrete, as their abrasion wear results were higher than 50%. The recycled concrete aggregates were considered as suitable for the use in the concrete production.

**Table 2.** Results of the Los Angeles abrasion test.

Samples	Weight Loss (%)	Upper limit for weight loss (according to NBR 7211 (ABNT, 2005))
Plaster CDW	80.18	
Ceramic CDW	59.06	< 50
Concrete CDW	46.94	
Basaltic Gravel	32.5	

Table 3 below presents the results obtained from slump test carried out on the fresh concrete produced with recycled and natural aggregates. The concrete with recycled aggregate of ceramic source presented higher slump, 42 mm. That may be as a result of the high water absorption presented by recycled aggregate of ceramic.

**Table 3.** Results of mixture consistency evaluated by the results of slump tests.

Material	Mixtures	Consistency (mm)
Plaster CDW	T1 – 1 : w : 75%g : 25%CDW	30.0
	T2 – 1 : w : 50%g : 50%CDW	33.0
	T3 – 1 : w : 0%g : 100%CDW	34.0
Ceramic CDW	T1 – 1 : w : 75%g : 25%CDW	38.0
	T2 – 1 : w : 50%g : 50%CDW	40.0
	T3 – 1 : w : 0%g : 100%CDW	42.0
Concrete CDW	T1 – 1 : w : 75%g : 25%CDW	35.0
	T2 – 1 : w : 50%g : 50%CDW	38.0
	T3 – 1 : w : 0%g : 100%CDW	37.0
Basaltic Gravel	T0 – 1 : w : 100%g : 0%CDW	40.0

According to Ismail et al. (2009) the main factors affecting the workability of recycled aggregate concrete are the higher rate of water absorption. This condition can affect the workability of the concrete mix that the recycled aggregate.

Table 4 shows the results of compressive strength of studied concretes at ages of 3, 7 and 28 days. According to the data, for all studied mixtures, the compressive strength values tend to increase, when compared to the reference mixture (T0 - 1:w:100%g:0% CDW), but the reference mixture has higher strength.

**Table 4.** Average compressive strength for the specimens (MPa).

Material	Mixture	Age/Compressive strength (MPa)			Strenght increase from 3 to 28 days (%)	Average Failure Strain Ratio (Ti/To) at 28 days
		3 days	7 days	28 days		
Plaster	T1 – 1 : w : 75%g : 25%CDW	16.2	18.7	29.3	81	80
Waste	T2 – 1 : w : 50%g : 50%CDW	14.8	17.5	27.1	83	74
	T3 – 1 : w : 0%g : 100%CDW	14.3	16.4	20.4	43	56
Ceramic	T1 – 1 : w : 75%g : 25%CDW	14.1	17.7	22.2	57	60
Waste	T2 – 1 : w : 50%g : 50%CDW	11.5	17.1	19.7	71	54
	T3 – 1 : w : 0%g : 100%CDW	7.3	12.6	16.2	122	44
Concrete	T1 – 1 : w : 75%g : 25%CDW	16.3	27.8	35.2	116	96
Waste	T2 – 1 : w : 50%g : 50%CDW	15.9	21.3	32.3	103	88
	T3 – 1 : w : 0%g : 100%CDW	14.5	16.4	27.0	86	74
Basaltic Gravel	T0 – 1 : w : 100%g : 0%CDW	17.9	28.6	36.7	105	-

All mixtures have shown an expressive gain in strength along the curing period. Between the third and the twenty-eighth day, this increase was higher for concretes containing 100% recycled ceramic aggregates (T3 - 1:w:0%g:100%CDW), nearly 122%; followed by concretes with 25% recycled concrete aggregates (T1 - 1:a:75%g:25% CDW), with 116%. As for the concrete with 100% natural aggregate (T0 - 1:w:100%g:0%CDW), this gain amounted to 105%. Figures 12, 13 and 14 illustrate the evolution of the concrete strength, according to the curing age.

It can also be noticed that the maximum compressive strength at the age of 28 days was achieved for the reference mixture. The compressive strength value obtained for this mixture was 36.7 MPa. The mixtures with recycled concrete aggregate showed compressive strength higher than the mixtures with recycled plaster aggregate. The mixtures with recycled ceramic aggregate shower compressive strength smaller.

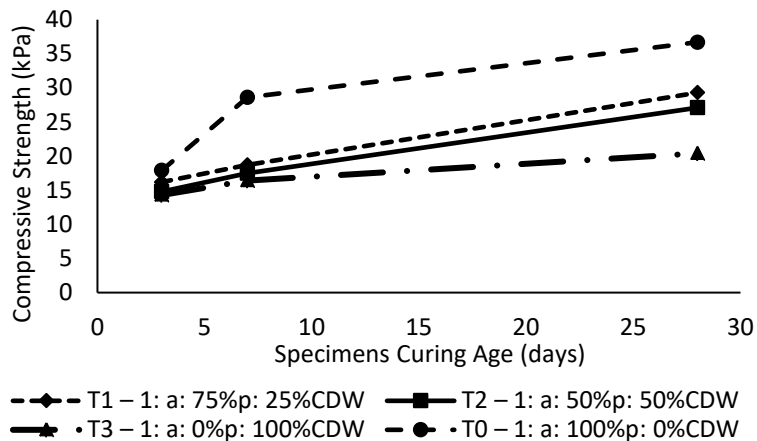


Figure 12. Gain of Compressive strength with time for the concrete manufactured with plaster aggregate.

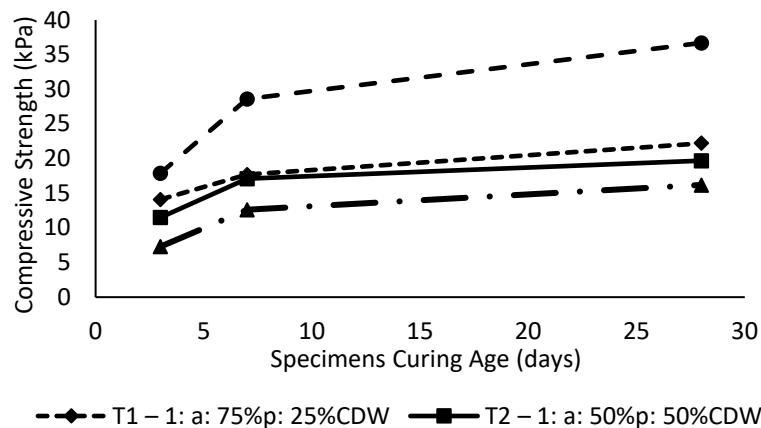


Figure 13. Gain of Compressive strength with time for the concrete manufactured with ceramic aggregate.

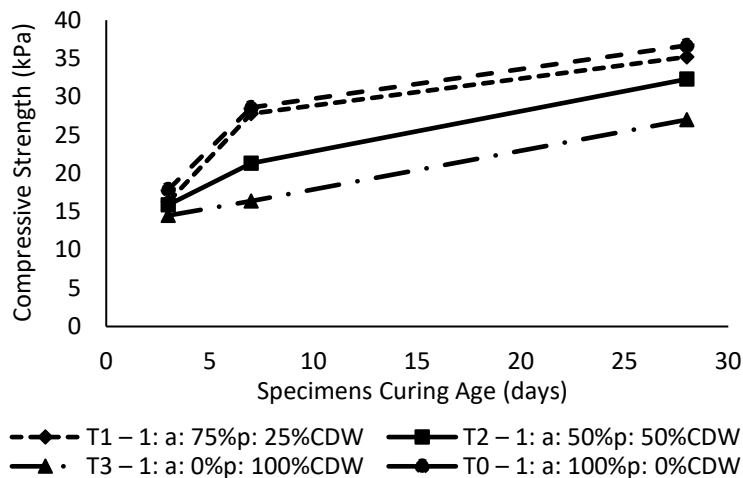


Figure 14. Gain of Compressive strength with time for the concrete manufactured with concrete aggregates.

Considering only the mixtures with recycled aggregates, the maximum value for the concrete compressive strength has occurred in the mixtures where 25% of the natural aggregates were replaced with recycled concrete aggregates, i.e., the mixture T1 - 1:w:75%g:25%CDW. This mixture showed compressive strength of 35.2 MPa at the age of 28 days. This value is higher than that established by the NBR 9781 (ABNT, 2013),  $\geq 35$  MPa, for pavements with traffic of usual vehicles. It represents 96% of the reference concrete strength. It can be observed in Figures 15, 16 and 17 that the compressive strength decreases with the increase of the percentage of recycled aggregate in the mixture for the three types of recycled materials used in this study.

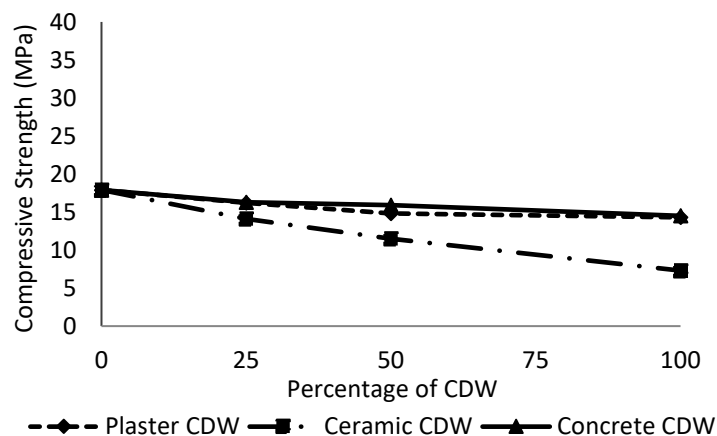


Figure 15. Concrete strength variation according to the percentage of recycled aggregate in the mixture (3 days).

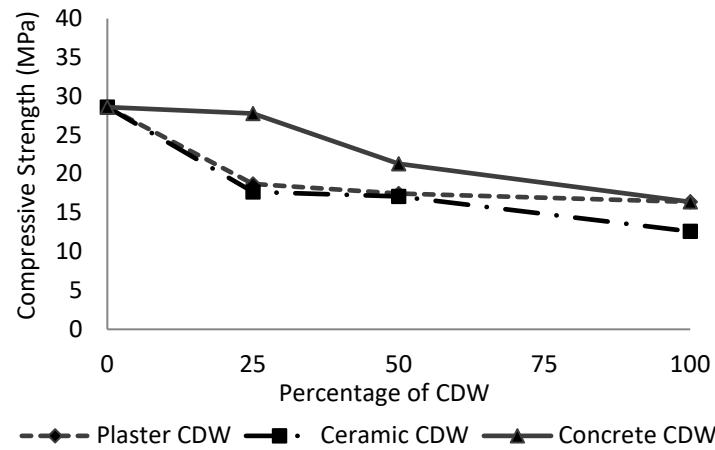


Figure 16. Concrete strength variation according to the percentage of recycled aggregate in the mixture (7 days).

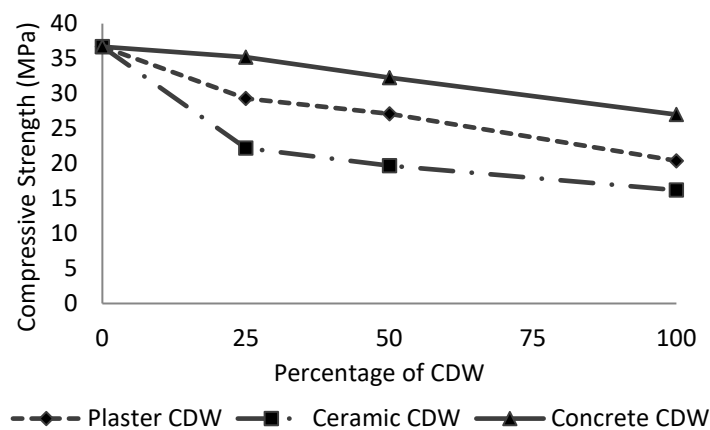


Figure 17. Concrete strength variation according to the percentage of recycled aggregate in the mixture (28 days).

### Conclusions

The experimental results achieved showed that the axial compressive strength for the concrete increases with time for all mixtures, from 3 to 28 days. This gain was more significant to the mixture with 100% of recycled ceramic aggregate.

The mixtures with recycled concrete aggregates showed greater axial compressive strength values than the mixtures with recycled plaster aggregates. These, in turn, showed strength values higher than the mixtures with recycled ceramic aggregates.



The axial compressive strength decreased with the increase in the percentage of recycled aggregate in the mixture, for the three types of recycled materials used in this study.

The highest axial compressive strength at 28 days was obtained with the mixture containing 25% by mass of natural aggregate (crushed basalt 0) for concrete residue. The obtained strength was 35.2 MPa, higher than the standard set by NBR 9781 (ABNT, 2013),  $\geq 35$  MPa, for pavements with traffic of usual vehicles, and it represents 96% of the reference concrete strength.

The concrete with recycled plaster and ceramic aggregates showed axial compressive strength lower than 35 MPa. Therefore, the tested materials cannot be used for manufacturing blocks for use in pavements with vehicle traffic, thus requiring other studies. However, they can be used to manufacture blocks for sidewalks, kerb blocks, subflooring layers and other elements in a non-structural role.

The results for the abrasion resistance, obtained for the natural aggregate and the recycled aggregate from concrete waste, indicate that these materials can be used in concretes. On the other hand, the recycled plaster and ceramic aggregates showed wear due to abrasion higher than 50% and are therefore not suitable for use in concretes.

The use of construction waste (CDW) as coarse aggregates in concretes, replacing the natural aggregate, has been proven to be quite feasible within the parameters evaluated in this study.

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