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The study of precast pavers production from concrete blocks waste

Estudo da produção de pavers para pisos intertravados utilizando resíduos de blocos de concreto

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Abstract

This work presents part of a study whose main objective is to observe the behavior of the physical and mechanical properties of the materials (raw material) and of products made for the civil construction from the precast concrete industry, such as concrete blocks and pavers for interlocking floors. Through the investigation, was identified the potential of using the concrete blocks waste of the production as aggregates added to the concretes utilized to produce pavers. Thus, it is expected that this work contributes as a basis for obtaining scientific and technical knowledge regarding the materials and procedures that must be adopted for the manufacture of pavers, allowing their production for commercialization.

Keywords: Technological development. Sustainable development.Pavers. Civil construction. Concrete blocks.

Resumo

Este trabalho apresenta parte de um estudo que tem como objetivo principal observar o comportamento das propriedades físicas e mecânicas dos materiais (matéria prima) e de produtos disponibilizados para a construção civil pelas indústrias de artefatos de cimento, tais como: blocos de concreto e *pavers* para pisos intertravados. Por meio do estudo desenvolvido foi identificada a potencialidade de utilização de resíduos da produção de blocos de concreto como agregados adicionados aos concretos utilizados para se produzir *pavers*. Dessa forma, espera-se que este trabalho contribua como base de obtenção de conhecimento técnico científico referente aos materiais e procedimentos que devem ser adotados para a fabricação de *pavers* possibilitando a produção para comercialização dos mesmos.

Palavras-chave: Desenvolvimento tecnológico. Desenvolvimento sustentável. *Pavers*. Construção civil. Blocos de concreto.

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Introduction

The environmental issue is increasingly being debated at the international, national, and local levels. Awareness about the environmental problems faced in the modern world leads to the demand for products and services developed through constructive and industrial processes aimed at the sustainable consumption of natural resources. It is necessary to adapt to a model of economic development capable of meeting current needs without compromising future needs.

The elevated production of solid waste, determined by the accelerated development of the worldwide economy, places the valorization of waste and recycling as inevitable. Civil Construction Waste (CCW) is a serious problem in major Brazilian cities. It is estimated that the average production of solid waste in Brazil varies from 450 to 550 kg for each inhabitant per year, which corresponds to approximately 50% of the solid urban waste mass (ANGULO; ZORDAN; JOHN, 2001; ANGULO, 2005; BUTLER, 2007);

The use of Civil Construction Waste (CCW) in the form of aggregates, both coarse aggregate and fine aggregate, has been the subject of numerous studies in recent decades, among the large number of works we can highlight: Ambrós *et al*. (2017), Angulo (1998), Angulo (2005), Damineli *et al*. (2016), Gomes *et al*. (2015), Gonçalves (2001), Levy and Helene (2004), Miranda, Vogt and Rocha (2019), Ulsen *et al*. (2013) and Zordan (1997, 2003), among others.

In a recent study to observe the context of structural masonry in the region of Londrina, PR, through visits in concrete blocks factories for application in structural masonry, it was observed that in the process of production of concrete blocks, there is a loss in part of the blocks produced, due to failures in the blocks pressing process or even due to the collapse of the block (total or partial) before the concrete hardened. These blocks, which cannot be sold, are stored in the companies' yards as production waste and does not have a specific destination.

Thus, because it is a clean waste being made exclusively of concrete, it was verified the possibility of developing materials and products out of recycled aggregates from these crushed concrete blocks waste. Therefore, a study was idealized in order to investigate the best applications for these residues.

In the development of this experimental study, one of the objects was the production of pavers using recycled aggregates obtained by crushing the concrete blocks waste, noticing their mechanical strength properties and porous structure.

Although techniques for recycling construction waste evolved at the end of the second decade of the 21st century, it cannot be said that recycling has become a widespread idea in the construction sector.

It should be noted that the development in the construction sector causes an increase in energy and raw material consumed and leads to the generation of waste causing an impact on the environment (BARDELLA, 2011).

In Brazil, the management of civil construction waste is foreseen in Resolution nº 307 of the National Environment Council - CONAMA (2002), with cities being responsible for defining a policy for Civil Construction Waste (CCW), being essential the recycling of the mineral origin fraction since it represents 90% of the CCW mass (ANGULO, 2005; ANGULO, ZORDAN; JOHN, 2001; BUTTLER, 2003).

The CONAMA Resolution nº 307 establishes four classes of waste, identified by classes A, B, C, and D, each one of these classes of waste is classified by the type of discarded material and what is its reuse potential. Among the four classes, Class A should be highlighted, which includes recyclable or reusable waste as aggregates (materials that can be aggregated in mortars or concrete).

It is known that the use of recycled aggregates in concrete is feasible, including the small fraction. However, its use in cement-based products is still small when compared to its potential for use. One of the aspects that limit the use of recycled aggregates in concrete refers to the heterogeneity of the composition and variability of physical properties (ANGULO, 1998; ANGULO, 2005; BUTTLER, 2003; GONÇALVES, 2001; LEVY; HELENE, 2004; ZORDAN, 1997, 2003).

Thus, inserted in the group called CCW, concrete waste presents a high potential for its use due to the knowledge of its basic properties, such as compressive strength and age, and its lower level of contamination by other materials when compared to other construction wastes. The leading generators of concrete waste are precast factories, cement artifacts factories, premixed concrete plants, demolition of buildings and road pavement (BUTTLER, 2003, 2007; GOMES *et al*., 2015; KATZ, 2003; TOPÇU; SENGEL, 2004).

Therefore, pavers, the study object of this work, Figure 1(a), are precast concrete pieces whose predominant use is ascertained in the construction of sidewalks and pavements, in which the surface layer needs to fulfill two priority properties: having a final touch that promote comfort for the transit of people and a structure that supports the loads that will be required, whether it is a light or a heavy vehicle (ABNT 2013b).

Figure 1 – Paver block.

(a) (b)

Source: (a) Google (2020); (b) The authors.

It is noteworthy that the term paver refers to the piece itself that represents the basic element, and the interlocking concrete floor, Figure 1(b), corresponds to the finished solution as a whole, is considered as the piece plus the base plus the confinement.

At the national level, due to the increasing usage of pavers, some rules went through recent revisions. Among them, we can highlight the NBR 9781 (ABNT, 2013) which deals with the testing methods of concrete pieces for paving, and NBR 15953 (ABNT, 2011) responsible for supervising the execution of the interlocked pavement with concrete pieces.

The NBR 9781 establishes the determination method of the compressive strength of concrete pavers, specifying the compressive strength of the paver with a value of 35 MPa for commercial vehicles and 50 MPa for special vehicles or requests capable of producing accentuated abrasion effects. The norm also determines the size of the sample to be tested for compression, which must be at least 6 pieces for lots of up to 300 m^2 of the produced floor and one additional piece for each additional 50 m^2.

The present study aimed to verify the possibility of incorporating waste from structural concrete blocks (blocks intended to produce structural masonry), as recycled aggregate added to the concrete mix used in the production of pavers. The process was conducted using the recycled aggregate with varying granulometry and also by replacing the natural aggregate for recycled aggregate with different proportions in the mixtures for analysis.

Thus, to verify the physical and mechanical properties of pavers, the generated wastes were collected from a company that produces concrete blocks for structural masonry, located in the city of Londrina, PR. Thereby, it was also analyzed the possibility of using the blocks crushed waste as recycled aggregates in partial and/or total replacement to the natural aggregates used in the concrete mixes to produce the pavers.

Methods and materials

This topic presents the materials and test methods used in the realization of the experimental work. This research was carried out at the Building Materials Laboratory of the State University of Londrina (UEL) and also in the premises of the cement artifacts production sector of the City Hall of the UEL University Campus.

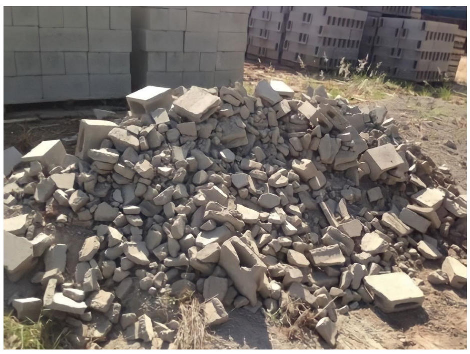
Portland Cement

The binder used in the production of the pavers was high initial strength Portland cement (CP V ARI), from a Brazilian source, corresponding to ASTM Type III cements. This is due to the need for a rapid demoulding of the materials produced, which is attended by the initial gain in compressive strength. In this way, the paver blocks demoulding occurred after 24 hours of production, showing a decrease in the deformation breaks and in the movement of the produced pieces.

Waste's aggregates from the cement artifact industry

The residues to produce recycled aggregates used in the experimental study were obtained in a concrete block industry located in the region of Londrina - PR. The waste from the production of the blocks was stored in the company's yard, Figure 2.

Figure 2 – Concrete block waste.

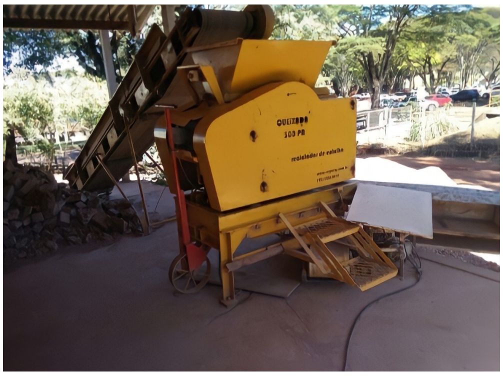


Source: The authors.

After gathering the material, it was transported to the City Hall of the UEL University Campus where it was crushed by a jaw crusher, called "Queixada 300", Figure 3.

After crushing the residues, they were separated into two different particle size for the recycled aggregates: a portion of apparently coarse aggregates

Figure 3 – Jaw crusher "Queixada 300.



Source: The authors.

(FM = 4.8 and MAS = 9.5 mm) and a portion of fine aggregates (FM = 3.4 and MAS = 4.8 mm). The recycled aggregates were stored in casks inside the Building Materials Laboratory of UEL. Figure 4 shows the image of the recycled aggregates obtained after crushing the concrete blocks showing the two granulometry obtained, where being in Figure 4(a) the size fine and 4(b) the size coarse.

Figure 4 – Particle size obtained after crushing the concrete blocks: (a) size fine and (b) size coarse.

(a) (b)

Source: The authors.

It is important to highlight that the recycled aggregates presented flaws in the flowing particle requirement, not showing an adequate flowing distribution for the particle size. However, for the analysis of the potential use of recycled material, it was decided to use it as it was present after the crushing process.

Natural aggregates

The natural aggregates used in the execution of the samples are those available and commonly used in the region of Londrina. Medium river sand was used, with a fineness module (FM) equal to 2.6 and crushed stone nº 0 (basalt) with a maximum aggregate size (MAS) of 9.5 mm. All materials were characterized according to Brazilian Standards.

Concrete Mixture Proportion

The concrete used for the pavers' production was mixture with a mass mix in the proportion 1:6 (cement: aggregates), this proportion was chosen because it is a mix very used by the cement artifact industries for the production of pavers. Thus, the reference mix using only natural aggregates was adopted in the following proportions: 1: 4.5: 1.5 (cement: sand: stone). The water/cement ratio for the reference mix was w/c = 0.20, this ratio was established because it attends to the requirements for concrete consistency for the production of pavers. Table 1 presents the reference mix and the concrete mixes produced with the recycled aggregates in the experimental study.

As C, S, and CS are the proportion of cement, sand, and crushed stone, respectively. Table 1 shows, for the concretes produced with recycled aggregates, different values for the water/cement ratio, this occurred so that all the concrete mixes showed the same consistency.

It should be noted that in the experimental study, a slump of 20 ± 5 mm was used for the concrete slump test, measured by doing the concrete slump test according to the procedure of NBR NM 67 (ABNT, 1998). The choice of the value for slump test mentioned is due to the fact that it is a consistency frequently used by the precast industries.

Observing Table 1, it is possible to verify that the concrete mix using recycled aggregate showed an increase in the amount of water to maintain the same consistency (increase in the water/cement ratio). This happens due to the higher value of the specific surface of the recycled aggregates when compared to natural aggregates (the smaller the particle size of the aggregate, the greater its specific surface and consequently the greater the surface area of water application).

Tests

All tests performed in the experimental analysis followed the Brazilian regulatory standards.

- Axial compressive strength test

The axial compressive strength tests were performed according to the procedures of NBR 5739 (ABNT, 2007). Cylindrical specimens of 10 cm in diameter and 20 cm in height were casting. After casting, the specimens were kept in a laboratory environment, and compressive strength tests were performed at the age of 28 days. Six specimens were casting for each concrete mix studied (all tested at the same age). The final result obtained for the axial compressive strength test of each mix studied was the average of the individual results of each specimen tested at the age of 28 days. The concrete crushing of the cylindrical specimens was carried out using a crushing table.

Table 1 – Concrete mixture proportion in the mass.

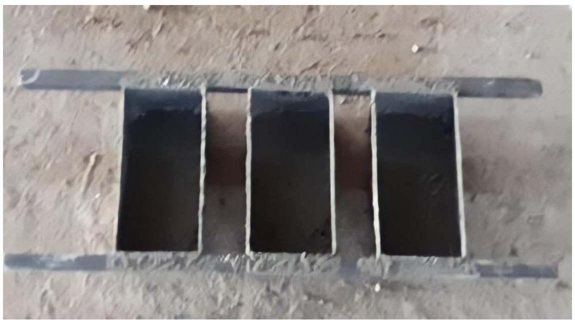
Mix	C	S	CS	Fine Aggreg	Coarse Aggreg	Ratio Water Cement
Reference	1	4.5	1.5	-	-	0.20
R1(50%)	1	4.5	0.75	-	0.75	0.65
R1(100%)	1	4.5	-	-	1.5	0.86
R2(50%)	1	2.25	1.5	2.25	-	0.58
R2(100%)	1	-	1.5	4.5	-	0.83

Source: The authors.

- Compressive strength and water absorption of pavers

The tests to determine the compressive strength and water absorption of the pavers were performed according to the procedures of NBR 9781 (ABNT, 2013). Prismal specimens of 10 cm x 20 cm x 6 cm (width x length x thickness) were casting in type 1 format. After the casting, the specimens were kept in a laboratory environment and the tests were carried out at the age of 28 days. For each concrete mix studied, six specimens were casting for compression rupture and six specimens for water absorption analysis. The concrete crushing of the specimens was carried out using a crushing table. Figure 5 shows the cast used in the production of the pavers.

Figure 5 – The cast used in the production of the pavers.



Source: The authors.

It is important to highlight that the manufacturing process of the pavers consisted of a rustic method of production. This happened because of the used cast, which, due to its straight edges between the side faces, making it difficult to demold the pavers and in some situations causing them to break in this step.

- Density of concrete

The tests to determine the density of the hardened concrete were carried out following the procedures of NBR 9778 (ABNT, 2005) with the saturation of the samples without boiling. The tests were performed at the age of 28 days using the cylindrical specimens (10 cm in diameter and 20 cm in height). The specimens were cured in a laboratory environment until the date of the tests. Four specimens were tested for each concrete mix. With the mass variation values (mass of the saturated and kiln-dried specimen) and also the mass of the saturated specimen immersed in water, the density values of the hardened concrete were determined.

Results and discussion

This topic presents the results obtained in the experimental work.

Axial compression strength

Table 2 shows the results of axial compression strength obtained with the concretes used to produce the pavers.

Table 2 – Axial compressive strength of specimens - MPa.

Mix	Resistance to axial compression (MPa)	Standard deviation (Sd)
Reference	10.5	0.62
R1(50%)	8.5	1.02
R1(100%)	3.0	0.71
R2(50%)	8.9	1.04
R2(100%)	7.7	1.23

Source: The authors.

From the analysis of the results presented in Table 2, it was verified that the use of recycled aggregate in concrete, both fine aggregate and coarse aggregate, both in partial and total replacement, generates a loss of compressive strength when compared to the reference mix produced using only natural aggregates. Therefore, regardless of the amount of recycled aggregate used in the concrete mix, the reference concrete mix, where only natural aggregates were used, showed higher values. Thus, it was observed that the largest amount of recycled aggregate used in the concrete mix, the lower the result obtained for compressive strength.

Similar results were obtained by other researchers in studies performed with concretes using recycled concrete aggregates where it was concluded that when the amount of recycled aggregate in the concrete mixture increases, there is a decrease in the compressive strength values of the concrete (COSTA *et al*., 2019; PIMENTEL *et al*., 2014).

It can also be observed in Table 2 that the concretes produced with the recycled aggregates of smaller dimensions showed better results than those obtained for the concretes with recycled aggregates of larger dimensions, especially in the direct comparison between the lines R1 (100% coarse recycled aggregate) and R2 (100% fine recycled aggregate).

Another aspect that influences the compressive strength of concrete is the type of curing and the curing time applied to the concrete, which has an influence on the hydration of Portland cement, influencing the porous structure of the concrete (BRESSAM *et al*., 2017).

Thus, it should be noted that due to the particle size distribution obtained by the recycled aggregates does not present a continuous distribution considered adequate, to maintain the same consistency obtained in the reference mix, it was necessary to increase the amount of water in the mixture mixes using the recycled aggregates.

The increase in the amount of water obviously causes loss of resistance to the concrete compression (also increasing the porous structure) being one of the factors that can justify the lower values for the compressive strength of the concrete produced with recycled aggregates when compared to the mix of reference.

In this perspective, there is an indication that, with the use of a more suitable granulometry for recycled aggregates, the values of the mechanical strength of concretes with recycled aggregates can be improved. According to Madrid *et al*. (2017) and Costa Junior and Pinheiro (2019), the compressive strength and water absorption of concrete using recycled aggregates is directly influenced by the physical and mechanical properties of the aggregates used in the mixture.

Compressive strength of pavers

The data on resistance to axial compression, collected through tests performed with pavers, was organized and presented in Table 3.

Through the analysis of the results in Table 3, it was observed that the use of recycled aggregates reduces the compressive strength of pavers in the same way that was observed for the compressive strength of concrete.

Table 3 – Compressive strength of pavers - MPa.

Mix	Compressive Strength of pavers (MPa)	Standard deviation (Sd)
Reference	6.1	1.70
R1(50%)	3.7	0.41
R1(100%)	2.8	1.10
R2(50%)	5.2	1.01
R2(100%)	4.4	0.84

Source: The authors.

In the same way that it was observed with the values of the compressive strength of concrete, pavers produced with recycled aggregates of smaller dimensions presented higher compressive strength when compared to pavers produced with recycled aggregates of larger dimensions R1 (100% coarse recycled aggregate) and R2 (100% fine recycled aggregate).

In the tests performed with the pavers, this observation was more evident than the result obtained in the tests with cylindrical specimens (Table 2). Thus, there is an indication that the gains in compressive strength are greater for pavers produced with recycled aggregates of smaller dimensions, this fact should be further investigated in future studies.

Regarding the compressive strength values for commercial pavers, NBR 9781 (ABNT, 2013) establishes that pavers for pedestrian traffic, light vehicles, and commercial vehicles must have a characteristic resistance to paver compression at the age of 28 days with a value greater than or equal to 35 MPa. Therefore, none of the studied mixes met this specification. This situation can be attributed to the fact that the reference mix assumed in the study is used by industries producing pavers with extrusion equipment, which results in a final product different from that produced in the research.

Pavers density and water absorption

Table 4 presents the results obtained for the density of the concrete mixes, produced with natural aggregates, and with recycled aggregates, and also the percentage of water absorption of the pavers produced.

Concrete with a pronounced amount of recycled aggregate showed higher water absorption and lower density. This can be attributed to the greater porosity of the recycled aggregate when compared to the natural aggregate (LIMA; LEITE, 2012).

Table 4 – Pavers density and water absorption.

Mix	Density of Hardened Concrete (Kg/m^3)	Absorption (%)
Reference	2051	6.33
R1(50%)	1934	8.82
R1(100%)	1810	9.87
R2(50%)	1970	8.92
R2(100%)	1920	10.66

Source: The authors.

Thus, both for the density and for the water absorption of the pavers, the values obtained are coherent with the literature on the subject. Another hypothesis that can be attributed is that the variation of values found can be attributed to the granulometric size differences and to the different values of the water/cement ratio used in each mix (COSTA JUNIOR; PINHEIRO, 2019; MADRID *et al.*, 2017).

Conclusion

This experimental work aimed to investigate the characteristics and potential for the reuse of concrete block waste to use as recycled aggregate in the production of concrete intended for the manufacture of pavers.

Through the obtained results, it was found that the waste of concrete blocks has great potential for its use because it is a clean waste, which does not present an excess of impurities when compared to traditional civil construction waste (CCW).

The results demonstrated that it is necessary to improve the granulometry size of the recycled aggregate produced, as variations in the aggregate granulometry result in the need to increase the amount of water in the mixture to maintain the consistency of the concrete and consequently reduce the mechanical strength of the concrete used to produce the paver block. Thus, it is necessary to pay better attention to the use of appropriate equipment in the waste crushing stage.

Likewise, the increase in the water/cement ratio in concretes using recycled aggregates resulted in pavers with greater porosity. This fact could be observed by increasing the percentage of water absorbed and decreasing the density of these concretes.

However, it has as a positive factor that the concrete block residues proved to be viable in the production of paver blocks, requiring continuity of studies to correct the granulometry and obtain concrete mixes that answer, as far as possible, the need of the production line of the precast industries that manufacture the pavers.

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