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ANALYSIS OF THE USE OF RUBBER FROM TIRE TREADING ON CONCRETE PAVERS

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ABSTRACT
Reusing tire rubber in concrete pavers is an environmentally sustainable alternative, reducing the exploitation of natural resources and contributing to solid waste management. Therefore, the research analyzed the replacement of natural aggregates with rubber waste from tire retreading. The replacement of fine aggregate with rubber occurred at percentages of 5%, 10%, and 15%, in which 160 pavers of each mix were produced. The moisture content of the concrete in the fresh state was analyzed to analyze the behavior of these modifications. In the hardened state, the pavers were subjected to compression resistance, abrasion resistance, impact resistance, total water absorption, specific mass and void index tests. The use of rubber waste proved a reduction of 47.39%, 51.83%, and 77.79% for composite pavers with 5%, 10%, and 15%, respectively, with the reference mix. Furthermore, positive and satisfactory results were obtained for abrasion and impact resistance tests.

Keywords: Concrete. Paver. Aggregate. Rubber.

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INTRODUCTION

Given the current scenario, where new products and technologies emerge daily, there is a constant search for the reuse of materials in civil construction. However, the role of professionals in this field is no longer just to plan and construct buildings, but also to be involved with society to seek new alternatives for the construction sector.

According to Canhada (2017), the use of discarded waste is increasingly being explored by civil construction, aiming to incorporate new properties into concrete. Fioriti et al. (2007) believe that using rubber from tire retreading in concrete pavers will reduce the consumption of aggregates from natural resource sources as well as the volume of tire waste deposited in landfills.

Freitas et al. (2009) report that 100 million unusable tires are in regular and irregular deposits in Brazil. Consequently, Resolution No. 258 of the National Environmental Council (CONAMA) requires tire manufacturers and importers to collect and properly dispose of them. Fernandes (2016) states that the main irregular disposal methods for tires include discarding them on public roads, open burning, and storing them where they come into contact with water.

According to Beumerink and Janssen (2001), the life cycle of a tire consists of five basic stages: extraction, production, consumption, collection of discarded tires, and waste management. However, after the end of its useful life, due to wear and tear, tires present a significant reverse logistics challenge, constituting an environmental liability that is difficult to dispose of (PELISSER et.al., 2011).

The generation, handling, and reuse of tire waste are regulated by federal laws and must be monitored by government agencies such as FNMA, IBAMA, and CONAMA. Environmental standards are outlined in ISO 14,000, and waste disposal is governed by NBR 10004 (NBR 10.004, 1987). Based on data provided by IBAMA (2023), in 2020, 460,000 tons of tires were properly disposed of and directed toward different types of applied technology, including co-processing, lamination, granulation, and industrialization.

According to Rodrigues and Santos (2013), recycled rubber aggregates from tires are very promising materials in civil construction due to their characteristics such as lightness, elasticity, energy absorption, and thermal and acoustic properties.

The reuse of concrete, aiming to replace aggregates, can play an important role in environmental preservation. In addition to reducing the exploitation of natural resources

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such as sand and gravel, it also decreases the accumulation of solid waste in inappropriate locations (ROMUALDO, 2011).

Granzotto (2010), after reviewing several studies, concluded that the use of rubber waste in paving blocks is a viable way to reuse discarded tires. Although there is a loss in compressive strength properties, the results regarding abrasion resistance are favorable for their use.

According to Marques et al. (2019), the use of rubber waste will benefit the construction sector as it would generate profit, support sustainable issues, and, like Fioriti et al. (2007), they believe it will reduce the disposal of tires in inappropriate places and decrease the extraction of natural resources.

Given the above, this research sought to evaluate the replacement of 5%, 10%, and 15% of fine aggregate with rubber waste in an industrial environment to make its application technically viable in a concrete artifacts company.

MATERIALS AND METHODS

MATERIALS

Portland cement CPV-ARI was used, with a specific gravity of 3.00 g/cm³ and an average compressive strength of 53 MPa at 28 days, conducted by the NBR 16605:2017 and NBR 16697:2018 standards (ITAMBÉ, 2023).

The fine aggregates used in the reference mix consisted of a composition of 60% river sand and 40% crushed aggregate. The river sand, sourced from the metropolitan region of Porto Alegre, has a maximum dimension of 4.8 mm and a fineness modulus of 2.49. The crushed aggregate, from quarries in the Serra Gaúcha region, has a maximum dimension of 2.4 mm and a fineness modulus of 2.24 (ABNT NBR 17054:2022, ABNT NBR 16916:2021, and ABNT NBR 16972:2021).

The coarse aggregate used is from the basalt rock crushing process produced in the Serra Gaúcha region. It has a maximum dimension of 12.5 mm and a fineness modulus of 5.89 (ABNT NBR 17054:2022).

The rubber aggregate from unusable tires was obtained in granular form and characterized as a fine aggregate, with a maximum dimension of 4.8 mm and a fineness modulus of 3.21 (ABNT NBR 17054:2022, ABNT NBR 16916:2021, and ABNT NBR 16972:2021).

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Tap water from the public supply network was used, and 0.3% plasticizer additive (based on the cement mass) with a density of 1.0 g/cm³ was added.

PAVERS PRODUCTION

A company in the Serra Gaúcha provided the mix design used for production. Determined through the ABCP method, the mix consists, by mass, of 1:5:0.4:0.45 (Cement, Fine Aggregate, Coarse Aggregate, water/cement ratio). This mix ratio is similar to that used by Pelisser et al. (2011). The composition has an average moisture content of 7.1%, consistent with Fernandes (2008), which suggests that cement artifact mixes should have between 5% and 8% moisture.

Following the approach of Marques et al. (2019), Monteiro Junior et al. (2019), Pelisser et al. (2011), and Fioriti et al. (2007), rubber replacement was chosen. Regarding the volume of fine aggregate, the adopted percentages were 0%, 5%, 10%, and 15%, respectively C. Ref, C. 5%, C. 10%, C. 15%.

The concrete was produced in a high-capacity planetary mixer. After mixing, the concrete is conveyed by a conveyor belt to the forming equipment, undergoing vibration and compaction processes.

After production, the pavers were placed in the curing cells of the company at ambient temperature, where they remained for approximately 24 hours. After the initial curing period, the pavers were removed and stored in a protected area at ambient temperature until the testing dates.

METHODS

The methodology used to obtain the results was developed collaboratively between the University of Caxias do Sul and companies in the Serra Gaúcha region, and is presented as follows.

Granulometric composition of concrete

The particle size distribution of the tested mixes followed Brazilian normative prescriptions (ABNT NBR 17054:2022, ABNT NBR 16916:2021, and ABNT NBR 16972:2021 ABNT NBR 17054:2022).

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Specific mass, water absorption, and void index

Following ABNT NBR 9778:2005, three specimens were used for the test execution. Initially, they were placed in an oven (105°C) for 72 hours to record the weight of the dry sample. Subsequently, the samples were immersed in water (23°C) for 72 hours to obtain the saturated mass. Using a hydrostatic balance, the immersed mass of the samples was determined. The values obtained were then applied in equations to calculate the respective results.

Compressive strength

According to ABNT NBR 9781:2013, 6 samples were used for each of the produced mixes. All samples were capped with mortar to smooth the surface. Subsequently, they were submerged in water 24 hours before testing. The pavers were tested at 4, 7, 14, 21, and 28 days after their manufacture.

Abrasion test

The abrasion test is described in ABNT NBR 9781:2013. This test is conducted using equipment where a disc comes into contact with the paver along with an abrasive material. Abrasion resistance is measured by the cavity formed. For this test, 3 samples were required.

Impact resistance

The impact resistance test was adapted from ABNT NBR ISO 10545-5:2017, following recommendations from Fioriti et al. (2007). Its purpose was to establish a parameter for evaluating the impact resistance of the mixes molded after 28 days of curing.

Equipment with a guide tube and a 0.5 kg metal sphere were required to conduct the test. The sphere is dropped freely onto the paver surface during the test.

RESULTS AND DISCUSSION

GRANULOMETRIC COMPOSITION OF CONCRETE

Figure 1 shows the particle size compositions of the mixes with 0%, 5%, 10% and 15% replacement.

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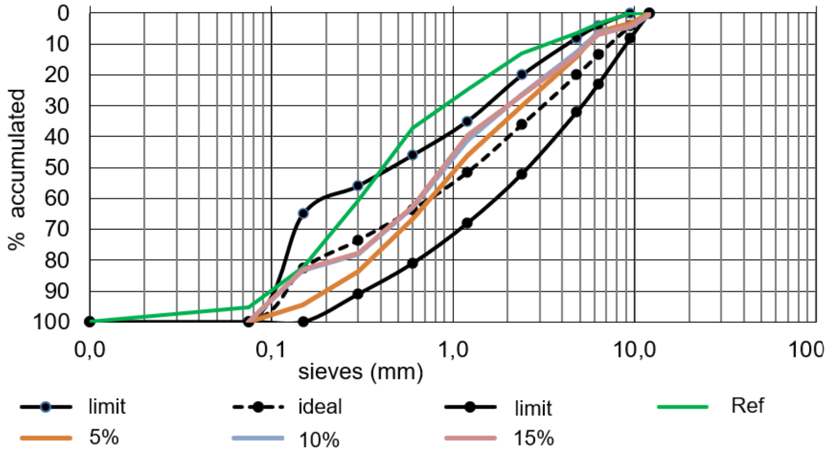
Figure 1: Granulometric curves of the compositions.

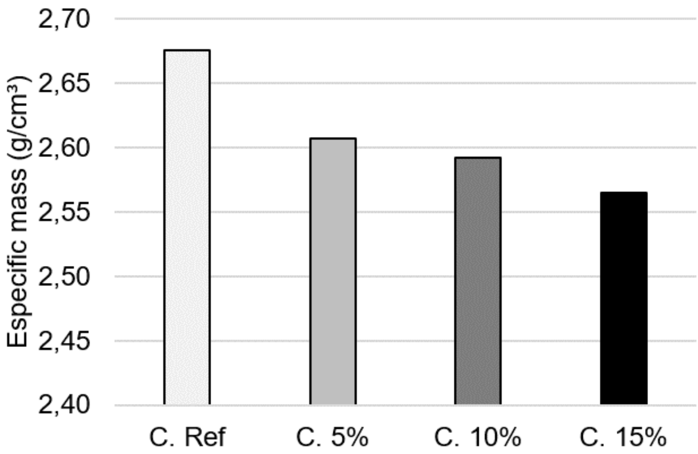


It can be observed that the reference trace (0%) is above the usable limit, showing discontinuity in the fine fractions. The mixes with replacement of 5%, 10%, and 15% have a particle size distribution close to ideal, showing particle size continuity with replacing the aggregate with rubber aggregate.

SPECIFIC MASS, WATER ABSORPTION, AND VOID INDEX

Figure 2 presents the results obtained for the real specific mass, in which a reduction in mass was found in the traces composed of rubber. The mixture containing 15% rubber showed a decrease of 4.11% in specific mass about the reference mixture.

Figure 2: Specific mass of the mixtures.



The values of 2.68 g/cm³, 2.61 g/cm³, 2.59 g/cm³ and 2.57 g/cm³ for the reference traces, 5%, 10% and 15% respectively. Higher than those found by Silva et al. (2019),

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where obtained results of 2.30 g/cm³ for the reference mix, 2.23 g/cm³ for the mix with 6% added rubber, and 2.26 g/cm³ for the mix with 9% of addition of rubber.

In the research by Pelisser et al. (2011), the reference mixture had a specific mass of 2.4 g/cm³, while the rubber mixture reduced its mass to 2.3 g/cm³.

In Figure 3, the results obtained for water absorption are presented, where from the analysis, it is proven that only the reference trace, with 5.09% water absorption, meets the requirements of ABNT NBR 9781:2013, in which the maximum absorption should be 6%.

The composite mixes with 5%, 10%, and 15% rubber showed an increase of 82.4%, 52.24%, and 85.31%, respectively, in water absorption. The average obtained was 7.89%. The values found differ from Fioriti et al. (2007), who in their study obtained an average water absorption of 3.58%

Figure 3: Water absorption of the mixtures.

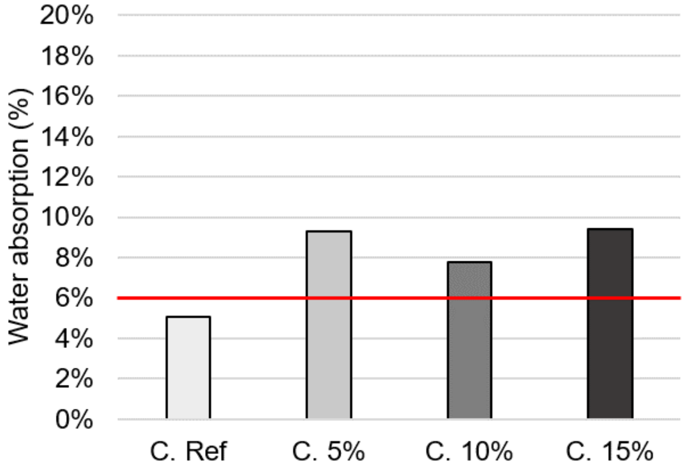

Figure 4 presents the results obtained for the void ratio test. It is noted that pavers composed of different percentages of rubber have a higher void ratio.

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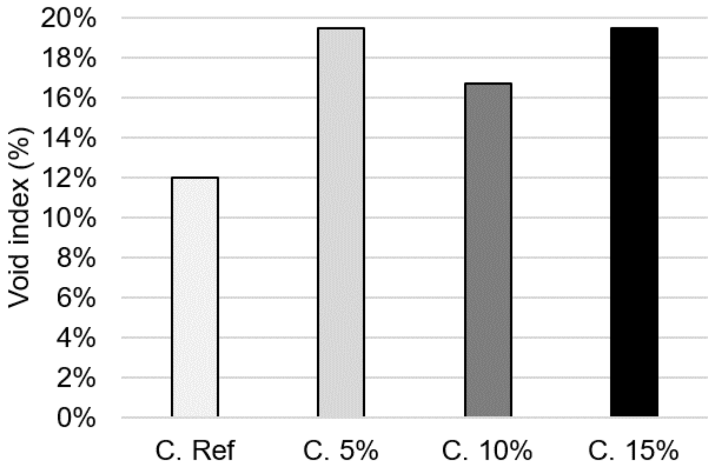
Figure 4: Void index of the mixtures.



The reference mix presented a void rate of 11.98%, while the mixes composed of rubber had higher percentages of space within the paver. The values found are 19.49%, 16.73%, and 19.48% for the traces with 5%, 10% and 15% of rubber, respectively. However, the increase in this parameter characterizes the increase in empty spaces within the paver, in which the compressive strength will be affected, causing its decrease.

The result found for the reference trait, 11.98%, is similar to that found by Silva et al. (2019), whose void rate was 12.06%. However, Silva et al. (2019) found results similar to the reference mix for the mixes with 6% and 9% added rubber, which differs from the increases obtained in this study.

COMPRESSIVE STRENGTH

The concrete pavers with the reference mix and with the mixes containing rubber were subjected to the compressive strength test on five different dates, with 4, 7, 14, 21, and 28 days, where in the pavers with rubber it was possible to observe a decrease in the compressive strength, as shown in Figure 5.

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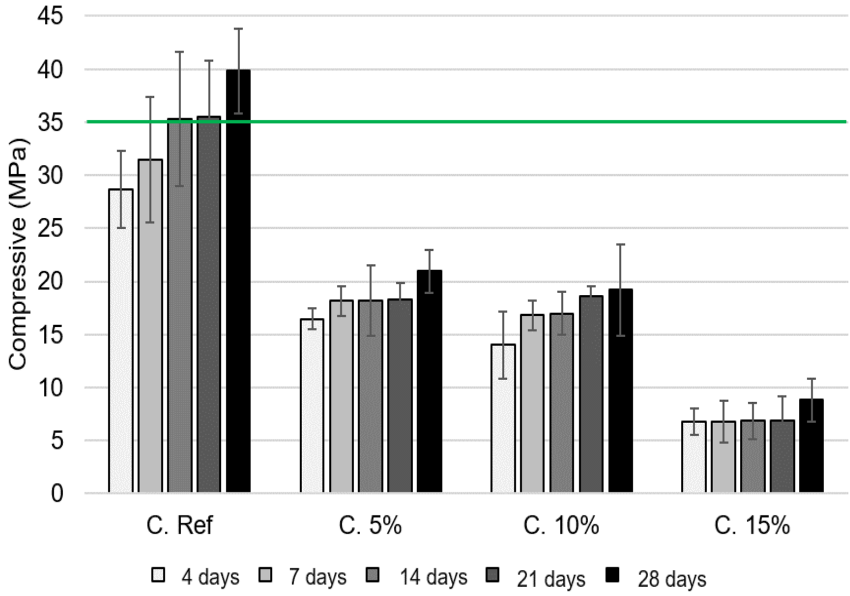
Figure 5: Compressive strength over time.



When evaluating concrete pavers, compressive strength is one of the most relevant properties, according to the ABNT NBR 9781:2013 standard, pavers require a minimum resistance of 35 MPa for locations where use is for pedestrian traffic, light, and commercial vehicles.

Therefore, pavers with rubber aggregates did not meet this criterion. In turn, the reference paver reached the minimum limit for this resistance class.

From the analysis of the results, it is possible to verify the reduction in compressive resistance in pavers using percentages of rubber. At 28 days, when the cement reached its curing time, the mixture using 5% rubber had a reduction of 47.39% compared to the reference mixture. In the mix containing 10% rubber, there was a reduction of 51.83% compared to the initial mix. For the last trait analyzed, with 15% replacement, there was a huge difference in resistance, reaching 77.79% about the reference trait.

According to Fioriti et al. (2007), the use of rubber waste, whose specific mass is lower than that of natural aggregate, causes the resistance property to be negatively affected.

According to Topçu (1995), the reduction in resistance can be attributed to the reduction in the quality of the solid material, whose capacity to withstand the load is lower, and due to the concentration of stresses in the paste that surrounds the rubber particles.

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Pelisser et al. (2011) when replacing 10% of the fine aggregate with rubber, found a 67% reduction in resistance, which is consistent with the result found with the mix analyzed in this work, which was 51.83%.

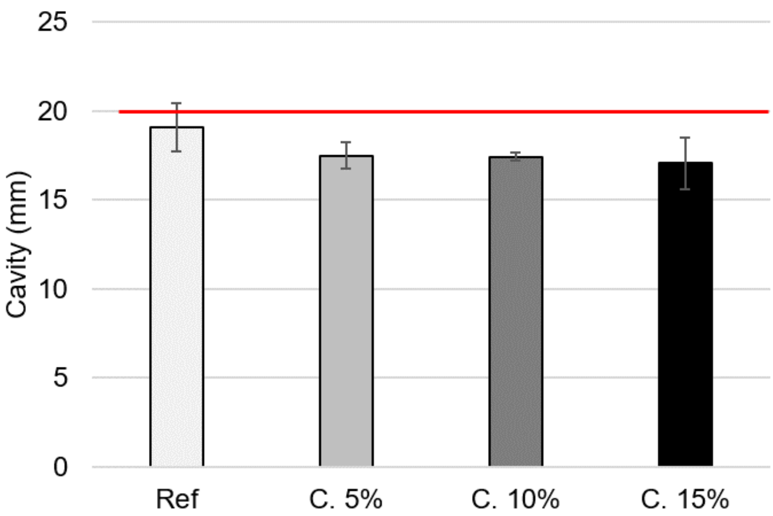
Despite the different concrete mixes used, the reduction in compressive strength is similar to studies carried out by Silva et al. (2019), Marques et al. (2019), Monteiro Junior et al. (2019), Pelisser et al. (2011) and Fioriti et al. (2007), where both found, in different percentages, a reduction in compressive strength.

ABRASION TEST

The abrasion test on concrete pavers aims to evaluate the durability and resistance of these pieces in real conditions of use. Therefore, the results obtained evaluate the paver's ability to maintain its integrity and appearance after exposure to intense traffic, climatic variations, and constant wear.

As shown in Figure 6, the test results, carried out over 28 days, were satisfactory, according to the ABNT NBR 9781:2013 standard, which, for accentuated abrasion effects, requires a maximum cavity of 20 millimeters.

Figure 6: Abrasion resistance at 28 days.



With the results obtained, it is possible to see that concrete pavers with different percentages obtained better results than the reference paver. The mix with the highest percentage of rubber replacement, at 15%, had 17.1 mm of the cavity, while the reference mix had 19.1 mm, thus presenting an improvement of 10.49% in abrasion resistance.

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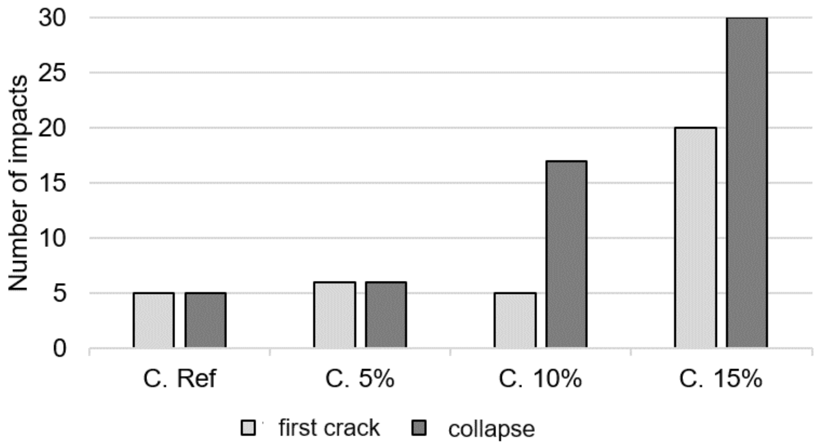
Thomas et al. (2016) mention that rubber particles promote increased abrasion, making it possible to use concrete pieces with these characteristics in floors and highway paving.

IMPACT RESISTANCE

Evaluating impact test results on concrete pavers can play a key role in understanding the ability of these pieces to resist shock forces. Through this test, it is possible to analyze how concrete pavers respond to concentrated loads.

As can in Figure 7, mixing with C. 10% and C. 15% required more impacts to reach failure, just as traces C. Ref and C. 5% reached failure when presenting the first crack. The analysis of the results found to obtain the first crack, a significant increase was noted in the mixture of 15% rubber, where 20 blows were needed to obtain the first crack.

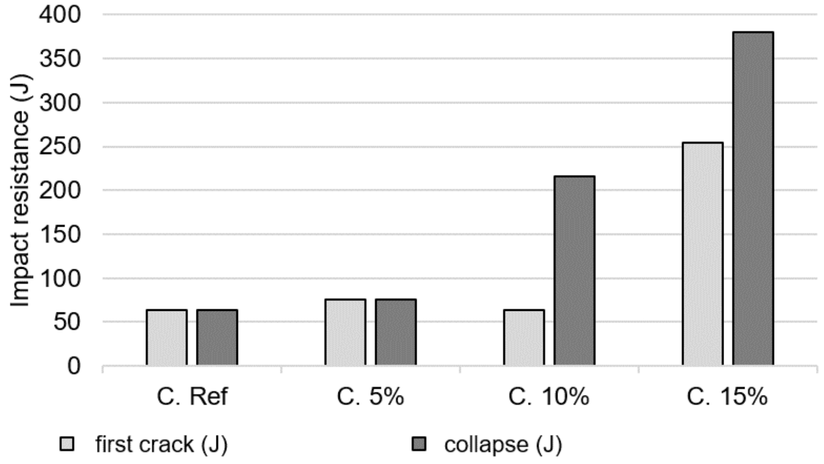
Figure 7: Impact resistance at 28 days.



The reference mix and, the compound mix with 5% rubber achieved total segregation when obtaining the first crack. For mixes with 10% and, 15% rubber, it took 12 and 10 more blows, respectively, to obtain total segregation.

Figure 8 presents the results obtained for impact resistance, which shows a significant increase in trait C. 15%. The energy required for rupture was 380.44 Joules, while for the reference mixture, the energy required was 63.41 Joules. The C. 5% mixture obtained a 20% increase in energy, resulting in 76.09 Joules and the C. 10% mixture obtained an energy of 215.59 Joules.

Figure 8: Impact resistance at 28 days (J).

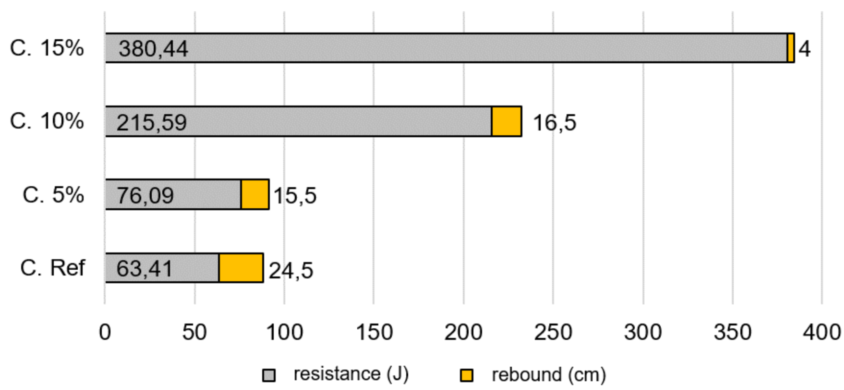


As shown in Figure 7 and, Figure 8, pavers containing the replacement of aggregate with rubber aggregate have a greater capacity for impact absorption. In line with the studies by Fioriti et al. (2007).

According to Granzotto (2010), rubber particles larger than 4.75mm make the concrete have greater ductility, therefore, there will be a higher deformation rate before the failure point. With improved properties, the paver will absorb a greater amount of energy, causing a ductile rupture to occur instead of a brittle rupture.

From the impact resistance test, it was possible to measure the rebound that the metal sphere produced. With the results found, it was possible to relate the resistance obtained with the rebound, as shown in Figure 9.

Figure 9: Relationship between impact resistance and rebound



From the results found, it is possible to relate the resistance of the paver to its energy absorption, since the reference concrete has the highest resistance and the highest rebound. Mixtures containing rubber aggregate absorb the energy of the sphere, generating a lower rebound height. The C.15% mixture obtained the lowest rebound height, being 4cm, 83.67% greater than C. Ref.

CONCLUSION

At the end of the research, it can be concluded that the results achieved demonstrate consistency and present connections with other studies that served as a basis in the preparation of this study.

The total water absorption test showed an increase in the amount of water absorbed in the rubber composite mixes. Through this, it was possible to establish an important relationship, which covers specific masses in dry and saturated conditions. The higher the specific mass, the lower the water absorption in the paver.

About the compression resistance test, a significant reduction in the resistance of pavers with percentages of rubber inserted was observed. Among the factors analyzed to explain this reduction is the fact that rubber has a lower specific mass, in addition to its particles being lamellar, which means that there is no perfect connection between the concrete and its surface. Another factor that is taken into consideration is the quality of the material, where the rubber does not withstand the same efforts as natural and, crushed aggregate. Furthermore, the reduction in compressive strength is directly linked to the reduction in the real specific mass of the concrete paver.

Regarding the abrasive behavior of concrete pavers, there is an increase in abrasion resistance in the traces using rubber. In general, the greater the percentage of rubber inserted into the paver, the greater the abrasion resistance obtained. This fact is related to the properties of rubber, which has the characteristic of increasing this index.

Concrete pavers using rubber have a greater energy absorption capacity. Among the factors analyzed to explain this property is the fact that rubber pavers require more impact, consequently more energy, to completely break the specimen. Furthermore, the rebound produced through the sphere also shows an increase in energy absorption,

However, the results obtained suggest that the addition of rubber to concrete pavers influences several properties, resulting in benefits in some aspects, such as abrasion resistance, but compromising compressive strength. These findings contribute to the understanding of the performance of these materials and provide valuable information for specific applications.

Finally, the use of this material can be a viable alternative in concrete elements without structural capacity. Among the possible benefits of using rubber waste in construction are the reduction of natural and crushed aggregates and the reduction of waste in the environment.

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