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A Comparative Analysis of Compressive Strength and Fracture Energy of Pervious Concrete

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Abstract: *Three permeable concrete admixtures were produced in order to analyze the variation that the adition of cement would cause in the characteristics: resistance to axial compression, specific mass, void index, permeability and the energy needed for the fracture. Thus, it was possible to verify that the strong admixture (1: 3,5) obtained the best mechanical characteristics, but lower permeability and voids index. On the other hand, the weak admixture (1: 6.0), due to the smaller presence of fines, was the one that obtained the worst mechanical characteristics and the best draining characteristics. The permeability coefficient varied between 3 and 7 mm/s, meeting the minimum requirements of NBR 16416 (ABNT, 2015) and the resistance to axial compression ranged between 3 and 9 MPa, which makes its use on sidewalks possible.*

1 Introduction

With the development of human societies, urban centers that previously needed large areas for their growth and establishment of their populations, became compact due to the verticalization of cities and the expansion of technology that allowed the agglomeration of these centers.

However, the concentration of people in a smaller space in the city results in saturation and fatigue of urban systems such as public transport, water treatment, sewage treatment and urban drainage.

As highlighted by Polastre and Santos (2006), the deficient planning of land use, due to the way in which cities were created, associated with the demographic explosion and the lack of adequate government policies to regulate urban growth, led to the occupation of areas necessary for balance fluvial regimes such as river floodplain areas.

Thus, one of the recurrent problems caused by this population accumulation in a region is the overload of the urban drainage system, which is responsible for the sustainable delivery of surface water to an adequate region in order to amortize the quantity and avoid floods and floods that damage the population.

According to Höltz (2011), the increase in urbanization and the consequent construction of buildings with sidewalks connected by paved streets, led to the covering of the urban area with impermeable materials that prevent the infiltration of water into the soil, overloading the urban drainage system.

The increase in waterproofed surfaces is also directly related to the decrease in the quality of water in the region. This is caused by pollutants and sediments that are present in cities and end up being transported to water bodies by rain. (BATEZINI, 2019)

In this way, the densification in large cities is capable of resulting in the almost total waterproofing of urban areas, and clearly indicate the need to use compensatory measures to recover the natural storage capacity. (BAPTISTA et al. 2005)

Thus, there is a need for devices capable of compensating the new demand for drainage systems and alleviating the system until it can balance itself without causing damage to society.

Included among the devices considered as compensating for the impacts of urbanization, the use of permeable pavements deserves to be highlighted as they have great potential for application both in terms of reducing the amount of drained surface water and in the possibility of acting as water reservoirs.

Permeable pavements are separated into 3 distinct generic types: porous asphalt concrete pavements; permeable concrete pavement; and permeable interlocking block pavement. (BATEZINI, 2013)

Among the possibilities of permeable pavements the one with the greatest potential for development are permeable concrete pavements due to the qualities of cement and concrete compositions, which have a wide range of development.

Therefore, in order to be able to mitigate and solve the problems caused by soil waterproofing, it is important that studies are carried out in this area that make it possible to enhance both the drainage characteristics of concrete, as well as the mechanical characteristics.

2 Literatura Review

2.1 Paving

The paving of traffic lanes is the main reason for the saturation of drainage systems and the possibility of applying measures capable of increasing the infiltration capacity of water to the ground could drastically reduce the disasters caused by lack of planning. (POMPEUS, 2005)

And for Tucci et al. (1995), urban planning and the choice of an adequate type of paving for urban areas are the only ways to avoid disasters, and the application of alternative forms of construction can help with other problems such as the replacement of aquifers.

Thus, Medina and Motta (2005) define pavement as a structure built on the surface obtained by earthmoving services with the main function of providing the user with safety and comfort, which must be achieved from an engineering point of view, that is, with maximum quality and minimum cost.

The floors are separated according to the type of mechanical behavior they are subject to and the materials in their composition, namely: flexible floors; semi-rigid floors and rigid floors.

2.1.1 Rigid Pavements

Rigid pavements are those whose bearing layer, that is, its coating, is composed of concrete and the types of pavements vary according to the techniques for handling the mixtures and the elaboration of the projects. (BALBO, 2009)

Among the rigid pavements are: simple concrete pavement (PCS); reinforced concrete pavement (PCA); concrete floors with continuous reinforcement (PCAC); prestressed concrete pavement (PCRO); precast concrete pavement (PCPM); “whitetopping” (WT) and pervious concrete pavements.

The differential of rigid pavements is that cement is part of its composition as the main binding component, thus, the control of hydraulic retraction in the mass of fresh concrete in large areas and volumes is important.

And, as pavements are large-scale works that are subject to unfavorable environmental conditions, such as sunlight and rain, they become subject to cracking and, to make the projects viable, concrete slabs with a determined geometric structure are delimited in order to respond to the loads imposed by the pavement.

For calculation purposes, when the pavement does not have reinforcement, the fundamentals and stress analysis models in these pavements require the hypothesis that the concrete works in an elastic regime, resisting all imposed efforts and avoiding consequent cracking and damage to the pavement by fatigue over a service or project time. (BALBO, 2009)

Thus, a limiting factor for the construction of concrete pavements is its strength, its ability to combat compression and flexural traction efforts, in addition to the fatigue caused by its use.

Therefore, to meet the strength requirements, the trend is to produce dense, impermeable pavements with a high mortar content.

For Tucci (1997), by meeting the mechanical characteristics necessary for its use, the pavement ends up becoming a practically impermeable material (since the presence of water under the concrete slab is not desired) and this causes undesired consequences for the environment such as: increase in surface runoff volume; increased frequency and intensity of floods; reduction of soil moisture and consequent decrease in the water table; decrease in the base flow of river channels; increase in the load of pollutants resulting from the urban drainage network;

In order to reduce the problems caused by paving, there is a need to develop methods that allow the population to move safely and comfortably, causing the least possible environmental impact and in a sustainable manner.

In this context, permeable rigid pavements, made of porous concrete, become a valid alternative, although limited due to their resistance, but with a great impact on society.

2.1.2 Pervious Rigid Pavements

Permeable pavements have, with limited features, the small presence of fine particles, such as sand, so that there is only a paste to cover the coarse aggregate, and thus, due to the low mortar content, they present a high void index and consequently high permeability .

Thus, Tennis et al. (2004) explains that a properly constructed permeable concrete can drain up to 200 liters of water per square meter per minute, that is, the equivalent of 34 millimeters of rain per second and that these values can be achieved without compromising the structural stability of the pavement.

Also according to Tennis et al. (2004), the benefits for the environment are not only related to the possibility of reducing the drained water, but also to factors such as the possibility of the pavements acting as reservoirs during the rainy season.

In addition, the drainage of water in natural soil helps in its natural filtration through the soil, and, due to the fact that cementitious concrete has a lighter color compared to bituminous concrete, it also absorbs less heat, which reduces the effect of heat accumulation in urban areas with high occupancy density.

For Xie et al. (2018) another important factor is the decrease in the amount of cement consumption per cubic meter of concrete, which results in a consequent decrease in the release of harmful gases during concrete hydration. In addition, with a lower consumption of cement, it is possible to obtain traces that, adapting to the use, are proportionally cheaper than those of conventional concrete pavements.

When compared to flexible, permeable pavements, it should be taken into account that the expenses with moving the soil to the lower layers of the pavement (subgrade, sub-base and base) generally entail high costs, which also makes the use of permeable concrete feasible. as a substitute. (ZHONG et al. 2018)

The advantage of permeable concrete, in relation to other forms of implantation of permeable pavements, is that, given the large void rate, the material, together with a gravel base, can store a large amount of water, helping to reduce the initial peak of many flood events.

When the material is properly sized, its degree of permeability is sufficient to allow the passage of all the precipitated flow in most rain events, practically canceling surface runoff. (HÖLTZ, 2011)

Due to the high porosity of permeable concrete, it can allow the passage of an amount of water that reaches 5080 mm/h per 0.09 m2, which translates into 11.4 to 19 l/min. (HUFFMAN, 2005).

The main point regarding the use of permeable pavement is the great improvement for the impacts seen during urban floods, allowing direct infiltration to the subsoil. On the other hand, once the reservoir is saturated with large volumes of precipitation, this pavement may present a reduction in its efficiency than that observed during the analyzes (ARAÚJO et al., 1999).

For Tennis et al. (2004) permeable concretes must contain a void index that is between 15% and 25% and a minimum permeability of 0.34 cm/s (approximately 200l/m^2/min). It is possible to obtain greater permeabilities since, varying the type of gravel, it is possible to increase the void index.

For the Brazilian Association of Technical Standards (ABNT), according to NBR 16416 (2015), a minimum permeability of 1mm/s and a minimum strength of 2 MPa is required in bending tensile tests for permeable concrete cast in place for the even be subject to light traffic.

3 Materials and Method

3.1 Materials

As mentioned in the previous chapters, the object of this work being the experimental dosage of permeable concrete, only three materials were used in the composition of the mixture: cement, coarse aggregate and water.

Cement

The cement chosen to compose the concrete dosage was CP II F-32, manufactured by CIPLAN. This type of cement is suitable for the production of permeable concrete because it has high resistance to sulfates, an important characteristic for concrete with a high void index, to be used in open-air paving of large surfaces. Table 1 below shows the main characteristics of the cement used in the dosage.

Table1 – Characteristics of the cement used in the mixture

Characteristic	Unit	Value
Specif surface - *Blaine* (NM 16372/2015)	cm^2/g	5000
Absolute specific mass at 20°C	g/cm^3	3,0
Cutting time (NM 16607/2018)	min	195-270
Compressive strenght (f_c)	MPa	15,0 (1 day) 23,0 (3 days) 28,0 (7 days) 33,0 (28 days)

Source: Manufacturer (CIPLAN), except for the specific mass which was tested by the authors

Coarse Agreggate

Crude 0 was used as coarse aggregate, from the Castilho-SP quarry, in the region of Ilha Solteira-SP. In Table 2 and Figure 1 below, the characteristics of the material used in the dosage will be presented.

Table 2 – Specif mass and the absorption of gravel 0

Characteristic	Unit	Value
Specif mass	g/cm^3	2,69
Absorption	%	3,03

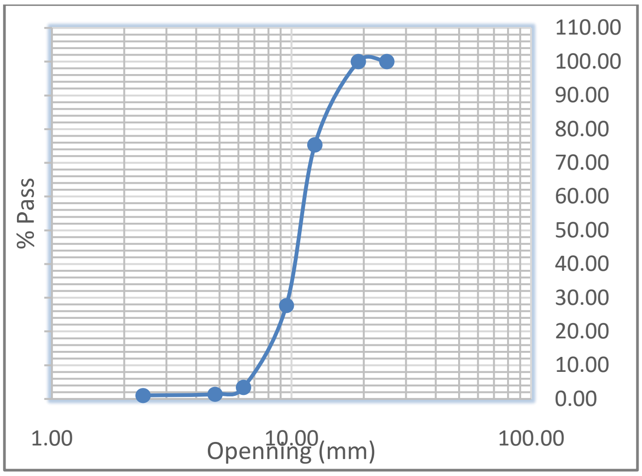


Figure1 - Gravel particle size curve 0

Water

The water used in the mixture was obtained via local public supply from deep wells.

3.2 Method

For the dosage and technological control of permeable concrete proposed in this work, an adaptation to the dosage method proposed by Helene and Terzian (1992) was used. The adaptation was fundamental due to the main characteristic of the concrete – permeability – where the fine aggregate had been removed from the mixture (comparing it to conventional concrete).

Helene e Terzian (1992) Method Adaptation

Basically, the adaptation was carried out so that the mixture's consistency and workability could be obtained. In the case of permeable concrete, the slump slump is expected to be 0. Therefore, knowing the minimum water/cement ratio for cement hydration (0.23) and aiming for a slump equal to 0, to all experimental dosages were considered a constant water/cement ratio of 0.25, where the difference between the water/cement ratio of the mixture and the water/cement ratio for cement hydration was 0.02. This added difference, the mixture was used to take into account the losses of water due to heat and water retained in the concrete mixer, for example.

In addition to the addition of 0.02 of water for losses, an additional percentage of water was added, which is intended for the absorption of gravel (3.03%), since the gravel used in the dosage was dry gravel in stove.

Experimental Mixing

Thus, once the water/cement ratio of the mixture is known and, in the absence of mortar, the steps proposed by Helene and Terzian (1992) for defining the ideal mortar content do not apply and, therefore, were disregarded.

Considering the correlation based on "Molinari's Law", the proportions of materials for conventional concrete are explained in Equation 1 below.

$$C_c = \frac{1000}{\frac{1}{\gamma_c} + \frac{a}{\gamma_a} + \frac{p}{\gamma_p} + \frac{a}{c}}, \text{ where} \qquad (1)$$

γ_c, γ_a e γ_c are the actual specific masses of cement, sand and gravel, respectively.

a, b are the masses (in kg) of sand and gravel, respectively.

C_c is the cement consumption in dm^3.

As soon as the properties of the materials are known and, applying the correlation of equation 1 as well as the exclusion of the portion referring to sand, the proportions of the materials are explained in Equations 2, 3 and 4, below.

Rich mixture

$$C_c = \frac{1000}{\frac{1}{3,00} + \frac{3,5}{2,69} + 0,25} = 530,66\, kg / m^3 \qquad (2)$$

Medium mixture

$$C_c = \frac{1000}{\frac{1}{3,00} + \frac{5,00}{2,69} + 0,25} = 409,49\, kg / m^3 \qquad (3)$$

Poor mixture

$$C_c = \frac{1000}{\frac{1}{3,00} + \frac{6,50}{2,69} + 0,25} = 333,27\, kg / m^3 \qquad (4)$$

For experimental study purposes, the concrete test at 28 days was foreseen. As proposed by the dosage method proposed by Helene and Terzian (1992), concretes with 1:3.5, 1:5 and 1:6.5 traces were tested.Table 3 is presented below with a summary of the basic characteristics of the present dosage study.

Table3 – Basic characteristics of the dosage study

Items	*Definitions (for age 28 days)*		
1. Number of mixture	1 – Rich	2 – Medium	3 - Poor
2. Structural elements where concrete will be applied	Pavement	Pavement	Pavement
3. Spacing between steel bars	-	-	-
4. Maximum characteristic dimension of the coarse aggregate adopted (mm)	9.5	9.5	9.5
5. Slump (mm)	0	0	0
6. Cement; brand, type and class	CPII F-32 CIPLAN	CPII F-32 CIPLAN	CPII F-32 CIPLAN
7. Maximum water/cement ratio (depending on the durability of the structure)	Não há	Não há	Não Há
8. Water/cement ratio as a function of dosage strength	0,36	0,40	0,44
9. Additions; brand, type and portion	-		
10. Age of rupture of specimens (days)	28	28	28
11. Estimate of loss of mortar in the concrete transport and casting system (%)	0	0	0
15. Trace (1:m:a1:a2) for the first experimental mixture (kg/kg)	1:3,5:0,25:0,106	1:5:0,25:0,152	1:6,5:0,25:0,197
Work: Experimental essay	Date: 2019-08-05		

4 Results and Discussion

As specified in the methodology, 3 concrete mixes were produced where what varied was the cement/coarse aggregate ratio. Therefore, the results of each trait were separated and then a comparative analysis between them was carried out.

In addition to the strength tests, additional analyzes were performed on the permeable concrete, including: the permeability coefficient; the specific mass; the void index and the fracture energy. The mechanical strength results obtained for the mixtures and their complementary analysis are shown int Table 4 to Table 9.

Table 4 - Axial Compression Strength - Proportion 1:3.5

CP	Maximum force (Kgf)	Compressive Strengt (MPa)
1	7880,12	9,84
2	3898,87	4,87
3	7536,91	9,41
4	9747,18	12,17
Average	7265,77	9,07
Standard deviation	2445,70	3,05

Table5–*Axial Compression Strength - Proportion*1:3,5

	k (mm/s)	μ (kg/m^3)	e (%)	Fracture Energy (J)
Average	3,25	2039,11	26,17	100,15
Standard deviation	0,20	77,86	0,73	26,17

Table 6 - Axial Compression Strength - Trace 1:5.0

CP	Maximum Force (kgf)	Maximum Voltage (MPa)
1	3006,53	3,75
2	3363,47	4,20
3	7578,09	9,46
4	6205,25	7,75
Average	5038,34	6,29
Standard deviation	2217,01	2,77

Table 7 - Complementary analysis - Proportion1:5,0

	k (mm/s)	μ (kg/m^3)	e (%)	Energia de Fratura (J)
Average	6,68	1894,35	35,14	73,23
Standard deviation	0,83	69,06	0,42	38,92

Table 8 - *Axial Compression* Strength - Proportion-Traço 1:6,5

CP	Força Máxima (kgf)	Tensão Máxima (MPa)
1	2320,10	2,90
2	2663,31	3,33
3	1537,58	1,92
4	2800,60	3,50
Average	2330,40	2,91
Standard deviation	565,86	0,71

Table 9- *Complementary analysis - Proportion*1:6,5

	k (mm/s)	μ (kg/m^3)	e (%)	Energia de Fratura (J)
Average	7,13	1792,96	39,92	29,15
Standard deviation	0,52	74,55	0,12	8,61

As suggested by Helene and Terzian (1992), dosage charts were created that together characterize the dosage diagram of permeable concrete dosed. The correlations are shown in Figure 2, Figure 3 and Figure 4.

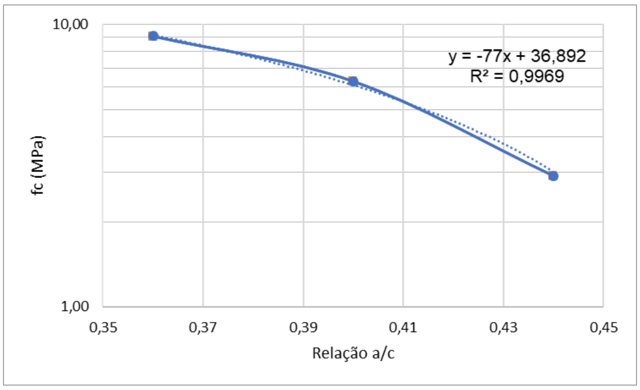


Figure2 - Correlation between Axial Compression Strength and the w/c Ratio

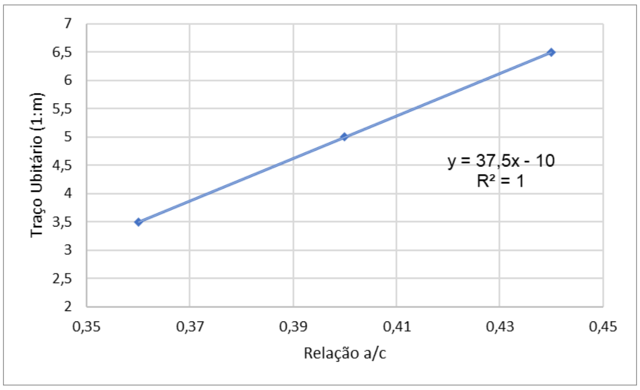


Figure2 - Correlation between the Unit Trace and the w/c Ratio

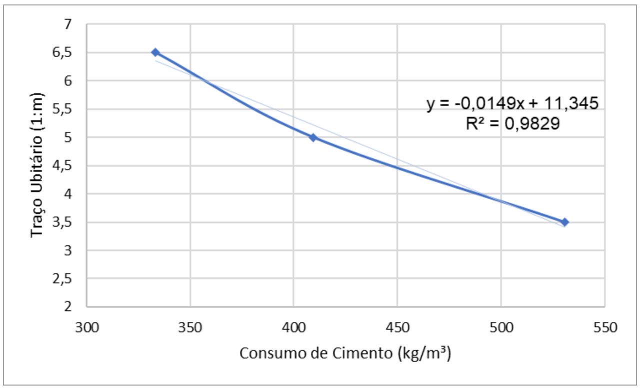


Figure3 - Correlation between Unit Trace and Cement Consumption

Finally, graphs were created in order to compare the parameters obtained between the unit traces. Comparison of compressive strength in relation to the unit mix is shown in Figure 5.

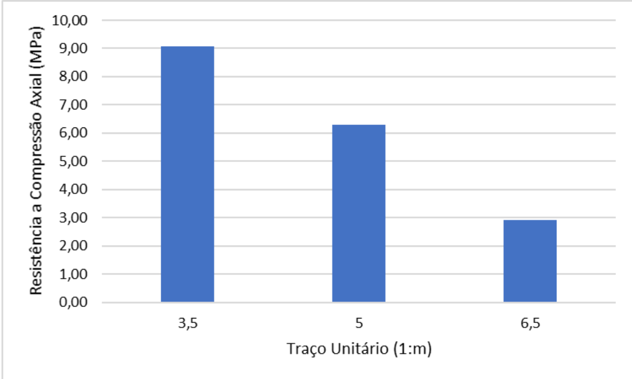


Figure4 - Unit Trace x Axial Compression Resistance

When comparing the unit mixes, it is possible to verify that, as the mix was weakened, the compressive strength also decreased, which when quantified presents a decrease of 30.67%, and of 67.90% of the 1:3 mix. 5 for the 1:5.0 and 1:6.5 traits, respectively. Furthermore, between the 1:5.0 and 1:6.5 traces the drop was 53.70%, which indicates that during this range the loss of resistance is greater and that the optimal working range is between the two traces stronger. The comparison of the specific mass in relation to the unitary mix is presented in Figure 6.

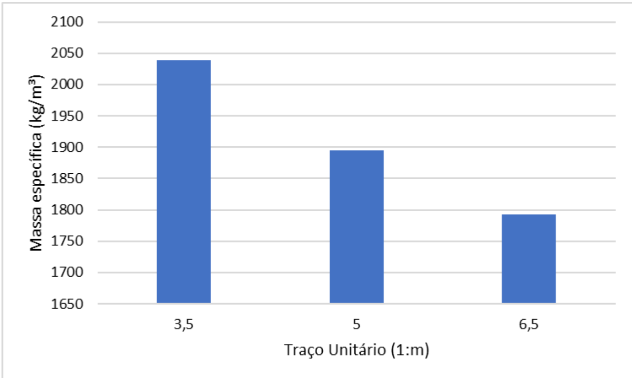


Figure5 - Specific Mass x Unit Trace

When comparing the unitary mixes, it is possible to verify that, as the mix was weakened, the specific mass also decreased, which when quantified presents a decrease of 7.10%, and of 12.07% of the mix 1:3.5 for the 1:5.0 and 1:6.5 traits, respectively. Furthermore, between the 1:5.0 and 1:6.5 traits the drop was 5.35%, which indicates that from this range onwards, the loss of specific mass tends to decrease. The comparison of the void index in relation to the unitary trace is presented in Figure 7.

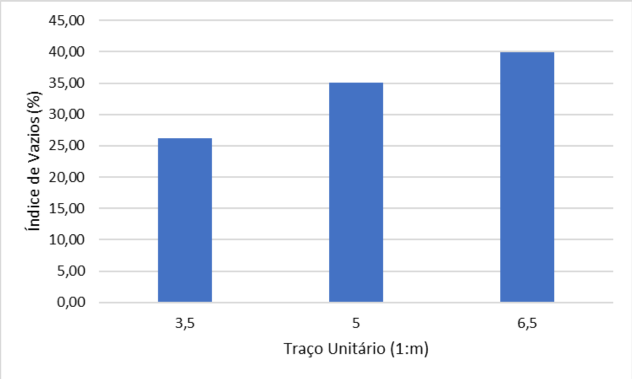


Figure6 - Correlation between Unit Trace and Cement Consumption

When comparing the unitary traces, it is possible to verify that, as the trace was being weakened, the void ratio increased, which when quantified presents a gain of 34.31%, and of 52.55% of the trace 1:3.5 for the 1:5.0 and 1:6.5 traits, respectively. Furthermore, between the 1:5.0 and 1:6.5 traces the gain was 13.59% which indicates that from this range onwards the gain of voids tends to decrease.

This indicates that the best range to work on is between the two richest, since it is possible to obtain a high void rate even between the strongest lines. The comparison of the permeability coefficient in relation to the unitary mix is shown in Figure 8.

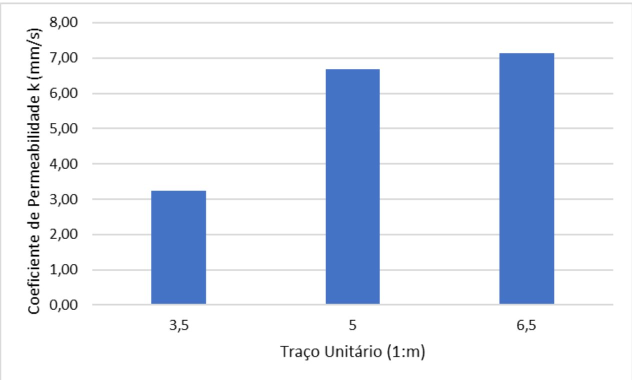


Figure7 - Permeability Coefficient x Unitary Trace

When comparing the unitary traces, it is possible to verify that, as the trace was weakened, the permeability coefficient increased, which when quantified presents a gain of 105.71%, and 119.35% of the trace 1:3.5 for the 1:5.0 and 1:6.5 traits, respectively. Furthermore, between the 1:5.0 and 1:6.5 traits, the gain was 6.63%, which indicates that from this range onwards, the permeability gain tends to decrease. The comparison of fracture energy in relation to the unitary trait is shown in Figure 9.

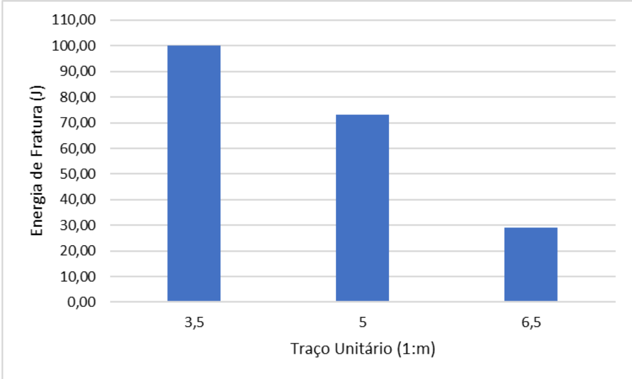


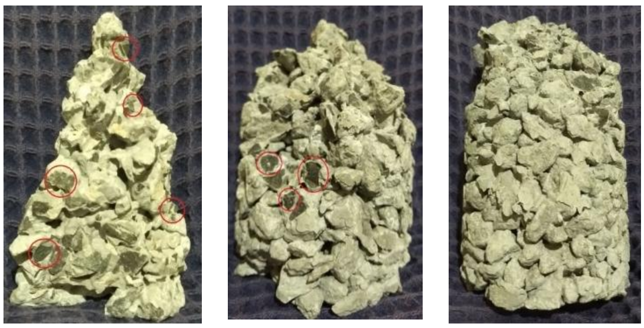
Figure8 - Fracture Energy x Unit Trace

When comparing the unitary features, it is possible to verify that, as the mix was weakened, the fracture energy decreased, which when quantified presents a loss of 26.88%, and of 70.90% of the mix 1:3.5 for the 1:5.0 and 1:6.5 traits, respectively. Furthermore, between the 1:5.0 and 1:6.5 traits the loss was 60.20%, which indicates that the range between the two strongest traits is the most suitable for working.

5 Conclusion

The analysis of the results showed that due to the low strength values obtained, this concrete could only be used as a pavement for pedestrians such as sidewalks, despite this, the minimum permeability and minimum void index values were largely met, which would give margin for the development of a stronger stroke with the addition of sand.

Furthermore, when performing the ruptures, it was possible to visualize, as shown in Figure 10, that in the strong line the rupture occurred in the coarse aggregate, which indicates that this aggregate did not react well to the varied efforts required by the heterogeneous concrete body. This is repeated in some parts of the medium-line specimens and did not occur in the weak lines, where all breaks were in the transition zone.



(a) (b) (c)

Figure9 - Proof bodies after Rupture

(a), (b) e (c) represent 1:3.5 traits; 1:5.0; 1:6.5, respectively.

Also in the mechanical analysis, it was possible to verify that there was a loss of 70.90% of the energy needed for the fracture of the specimen when comparing the weaker and stronger traces. This loss was smaller when comparing the strongest traits and this demonstrates that between the two it is the best range to work with.

As for the permeability and void index results, both were met, with the minimum 1mm/s and 15%, respectively, which indicates that the possibility of thickening the mix with the addition of fine materials (sand, silica, microsilica) is an alternative to seek greater resistance.

For the specific mass of hardened concrete, according to NBR 9778 (2005), the strong mix was classified as normal concrete (between 2000 kg/m^3 and 2800 kg/m^3) and the two weakest mixes as light concrete (below (2000 kg/m^3).

Finally, cement consumption was excessive in the strongest mix, above 450 kg/m^3, which would make its use unfeasible. On the other hand, a way to solve it would be a decrease in gravel granulometry or the adoption of intermediate mixes between the medium and strong, thus, it would be possible to find a trait in which the best mechanical performance in relation to the cost is obtained.

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