Study of the use of kaolin waste as a partial substitute for fine aggregate in the production of concrete for pavers

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ABSTRACT
The study of the use of kaolin waste has scientific and socio-environmental value by providing an appropriate destination, reducing the demand and consequent problems arising from its extraction, considering that the construction industry is a consumer of a significant amount of raw material. Thus, the study aims to replace the fine aggregate by kaolin waste in the proportions of 10%, 20% and 30%, verifying its feasibility for interlocking sidewalk pieces. The kaolin waste was used with and without fine material, and physical characterization tests of the materials were performed, and then the concrete pieces were subjected to tests of resistance to simple compression, water absorption and resistance to abrasion, as prescribed by ABNT NBR 9781:2013, and flexural tensile strength test, according to ABNT NBR 12142:2010. According to the results and analyzing the compressive strength at 28 days, the mixtures with replacement of 10% of fine aggregate by kaolin waste reached strengths greater than 35 MPa, an acceptable normative parameter, both for the waste with fines and without fines, making its use feasible.

Keywords: Paver, Mining Residue, Concrete, Kaolin.

1 INTRODUCTION

The interlocked sidewalk is gaining more and more space on roads and sidewalks around the world, because besides its aesthetics, it provides ease of execution and maintenance, thermal comfort, immediate release for traffic, among other advantages. In Brazil, according to Portland (2010), this type of sidewalk arrived in the 70's and is used in sidewalks, squares, parks, patios and streets.

The interlocked sidewalk is composed of several layers in order to receive and distribute the loads requested by people and/or vehicles. The overlay is made up of concrete pieces arranged in such a way as to form an interlock with each other (Knapton, 1976). The pavers are laid on a thin layer of sand or stone powder as a way of regularizing the surface that will receive this coating, besides also being grouted with these granular materials, providing greater permeability to the sidewalk and facilitating maintenance. These pieces are confined by containment devices, such as curbs, on their edges (ABNT, 2011).

Brazil is one of the richest countries in raw materials, where mineral extraction occupies a very important position in the economy (Silva, 2017). However, the extraction of one of the most consumed raw materials in the world, sand, brings enormous social and environmental damage, such as the modification and pollution of waterways and degradation of forests, motivating the search for alternative solutions to alleviate this situation.

On the other hand, kaolin is a mineral widely used in paper, plastics, paints, ceramics, support for catalysts and various other applications (Bertolino et al., 2012). The waste resulting from its processing is almost always disposed of in the open, not meeting the requirements for the use of landfills and causing serious environmental problems, affecting the physical and biotic environment, and social problems, causing damage to the health of rural residents who live near these "deposits" (Menezes, et al., 2009).

Given this, several types of waste and alternative materials are studied as substitutes for fine aggregate in concrete, with the purpose of also giving a new use to these materials that are often discarded in nature, thus reducing the impacts caused by this bad destination.

Therefore, this work aims to evaluate the use of kaolin waste as a partial substitute for fine aggregate in concrete for use in the manufacture of pavers, analyzing the compressive strength, abrasion resistance and water absorption of the pieces, according to the technical standards required by the current standard, proposing an appropriate application for this waste.

The cement used in the production of the pavers was CP V ARI, widely used in concrete for the manufacture of precast, because it gives high strength at early ages, providing a quick demolding and a minimum time of storage of the artifacts in the industries. The fine aggregates for making concrete were used sand and stone powder as fine aggregates, while the coarse aggregate was used gravel 0, both purchased in Campina Grande, PB.

About the kaolin residue used was obtained from a company located in the rural area of Junco do Seridó - PB. The kaolin waste with fines was used, without alteration in the granulometric composition, and the waste without fines, where the material passing the sieve with mesh opening of 0.075 mm was removed.

The water used was obtained from the water supply network of the Water and Sewage Company of Paraíba (CAGEPA), at room temperature and quantity defined by the mix used. According to NBR 15900-1 (ABNT, 2009), public supply water is suitable for use in concrete and does not need to be tested.

2 MATERIALS AND METHODS

The characterization of the materials was performed, determining the percentage of sand and stone powder used in the constitution of fine aggregate, the w/c ratio, the composition of the reference mix and the levels of use of kaolin waste. With this, the reference pavers were produced in order to be submitted to physical and mechanical tests.

2.1 MATERIALS

The standards and tests required to perform the characterization of the materials are shown in the following table

Table 1 - Testing Methods of Material Characterization and Standards

Testing Material Characterization Methods	Stansdarts	Material
Cement fineness	ABNT NBR 11579. (2013)	Cement
Specific mass of cement	ABNT NBR 16605. (2017).	Cement
Particle size analysis	ABNT NBR NM 248. (2003) e ABNT NBR 7211. (2013).	Coarse, Coarse and Waste Aggregate
Unit mass	ABNT NBR NM 45. (2006).	Coarse, Coarse and Waste Aggregate
Specific mass and water absorption of aggregates	ABNT NBR NM 52. (2009), ABNT NBR NM 30 (2001) e ABNT NBR NM 53 (2009).	Coarse, Coarse and Waste Aggregate

Source: authors,2021

2.2.2 Paver molding

The mix compositions were based on the work of Helene and Andrade (2005) and Rodrigues (1983).

The pieces were molded in prismatic PVC molds with dimensions of 20 cm x 10 cm x 6 cm, properly cleaned and greased with release agent. The concrete was mixed in a concrete mixer and compacted in a vibrating table, with execution times adopted according to the visual analysis of the mixture.

Initially, pavers were produced with substitution of 10%, 20% and 30% of fine aggregate (sand and stone powder) for kaolin waste with fines and the same levels of substitution with kaolin waste without fines. With this, the compressive strength test was performed at seven days of curing, in order to evaluate which residue content would present a better resistance.

After the rupture of the pieces with seven days of curing, pavers were made, for curing ages of 7 and 28 days, with the reference mixture and with the mixtures that presented the best results of compressive strength at seven days for each residue (kaolin with fine and without fine). Subsequently, they were subjected to tests for dimensional evaluation and water absorption (physical characterization) and compressive strength.

2.2.3-Dimensional evaluation

The dimensional evaluation of the pavers was performed with the use of a pachymeter, always taking the measurements in planes perpendicular or parallel to the edges of the pieces, according to their typology.

2.2.4 Water absorption

Initially, the pavers were immersed in water at a temperature of (23±5) °C for 24 hours. Then, the surface water was removed from the specimen with a damp cloth and weighed them individually. The process was repeated every 2 hours until the difference in mass was no greater than 0.5% from the previous value. With this, the saturated mass $m2$ was determined.

The concrete pieces were placed in the oven at a temperature of (110±5) °C for 24 hours. Subsequently, the pieces were weighed individually and the process was repeated every 2 hours until the difference in mass was no greater than 0.5% from the previous value, and the saturated mass value $m1$ was noted.

The calculation of water absorption in concrete paving pieces was obtained through Equation 1.

$$A(\%) = \frac{m_2 - m_1}{m_2} * 100 \quad \text{(Eq. 1)}$$

Where $m1$ is the dry specimen mass, in grams, and $m2$ is the saturated specimen mass, in grams.

2.2.5 Characteristic compressive strength

The value of the part's compressive strength, in MPa, is given by the ratio between the breaking load, in N, by the loading area, in mm², multiplying the result by the multiplicative factor p, in function of the part's thickness, according to Table 2.

Table 2 - Multiplying factor p.

Nominal partthickness (mm)	**p**
60	0,95
80	1
100	1,05

Source: ABNT NBR 9781:2013

Thus, the characteristic compressive strength estimated is given by Equation 2.

$$f_{pk,est} = f_p - t * s \quad \text{(Eq. 2)}$$

Where:

$$s = \frac{\sqrt{\Sigma(f_p - f_{pi})^2}}{n-1} \quad \text{(Eq. 3)}$$

fp is the average strength of the pieces, in MPa; fpi is the individual strength of the pieces, in MPa; n is the number of pieces in the sample; s is the standard deviation of the sample, in MPa; t is the Student's coefficient, as a function of sample size, provided by Table 3.

Table 3: Student's coeficiente

n	t
6	0,92
7	0,906
8	0,896
9	0,889
10	0,883
12	0,876

Source: ABNT NBR 9781:2013

3 RESULTS AND DISCUSSIONS

3.1 CHARACTERIZATION OF MATERIALS

3.1.1 Fineness and specific mass of cement

Table 4 shows the values that were found from the fineness index tests, according to NBR 11579 (ABNT, 2013), and specific mass, according to NBR 16605 (ABNT, 2017).

Table 4 - Fineness index and specific mass of cement CP V ARI

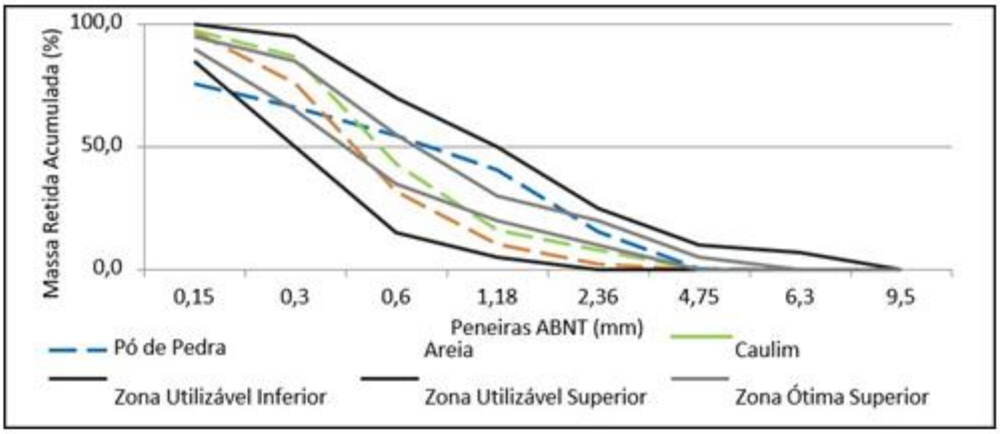
Test	Obtained Value
Fineness Index	0,22%
Specific Mass	3,05 g/cm³

Source: Souza, 2019.

The determination of the specific mass of the cement is necessary for the calculations of the concrete mix used. The fineness of the cement used was 0.22%, meeting the requirements of the standard, which suggests that the fineness index of high initial strength Portland cement, CP V - ARI, should be less than 6%.

3.1.2 Particle size analysis

Figure 1 shows the granulometric curve of the sand, the stone powder, and the kaolin, which represent the fine aggregates that will be used in the preparation of the interlock.



The fineness modulus and the maximum characteristic dimension of the kaolin waste were, respectively, 2.51 and 4.75 mm, fitting in the optimum zone, enabling its use as fine aggregate and the sand presented a fineness modulus of 2.17 and a maximum characteristic dimension of 2.36 mm.

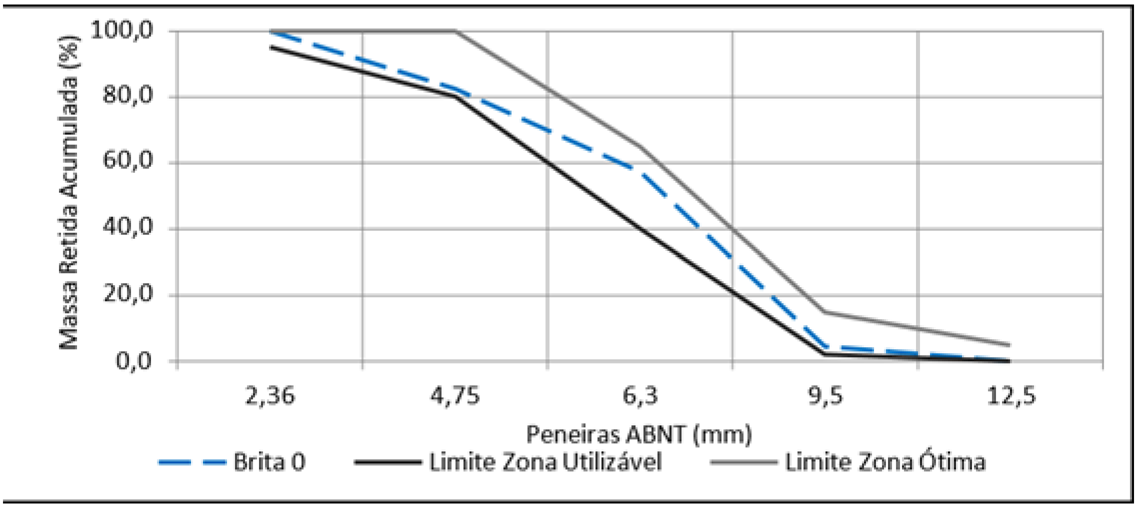
The fineness module of the stone powder is 2.52 and the maximum characteristic dimension of 4.75 mm. According to its fineness modulus, the stone powder is in the optimum zone.

Analyzing its granulometric curve, the stone powder presents a large amount of fines that pass through the sieve with mesh opening of 0.15 mm and a large amount of material retained on the sieve with mesh opening of 1.18 mm. On the other hand, the granulometric curve of the sand shows that this aggregate presents a small amount of material passing through the sieve with mesh opening of 0.15 mm and a small amount of aggregate retained on the sieve with mesh opening of 1.18 mm.

Analyzing the granulometric composition of the mixture of these two aggregates, it is possible to observe that the granulometric curve is totally in the optimal zone. This shows that the small amount of sand grains with dimensions of 1.18 mm is compensated by the stone powder, which has enough material with this granulometry, so that makes this mixture ideal to be used as fine aggregate in concrete.

The particle size distribution curves of the mixtures with partial replacement of the fine aggregate by 10% of the waste with fine (CF10%) and without fine (SF10%) are presented. Figure 2 shows the particle size curve of gravel 0, as recommended by NBR 7211 (ABNT, 2009).

Figure 2 - Grain size curve of gravel 0.



Source: Souza, 2019.

The aggregate presented a fineness modulus of 5.86 and a maximum characteristic dimension of 9.5 mm, reinforcing its characterization as gravel 0.

3.1.3 Unit Mass

Table 5 presents the unit mass values of the aggregates used in the production of concrete, according to NBR NM 45 (ABNT, 2006).

AGGREGATES.	UNIT MASS (G/CM³)
SAND	**1,43**
STONE POWER	**1,72**
KAOLIN RESIDUE	**1,08**
GRAVEL 0	**1,61**

Source: Authors

3.1.4 Specific mass and water absorption of aggregates

The results of specific mass and absorption of the fine aggregates are shown in Table 6.

Table 6 - Specific mass and absorption of fine and coarse aggregates

Aggregate	Gravel 0	Sand	Stone power	Kaolin Residue
Apparent Specific Mass (g/cm³)	2,63	2,26	2,41	2,25
Specific Mass Saturated Surface Dry (g/cm³)	2,65	2,32	2,47	2,38
Specific Mass (g/cm³)	2,67	2,40	2,56	2,58
Absorption (%)	0,51	0,60	0,80	-

Source: Authors

The kaolin waste has a lower apparent specific mass compared to sand and stone powder, showing that this waste has a greater amount of voids, contributing to greater water retention.

3.2 COMPOSITION OF THE MIX

With the results of the material characterization, the calculations were made to determine the conventional mix. Table 7 shows the mass mix used for the production of the pavers, calculated according to the required strength and the specifications of the materials used.

Table 7 - Mass mix for the reference concrete.

Cement	Fine aggregate	Coarse aggregate	Water
1	1,8	2,8	0,6

Source: Souza, 2019.

The amount of each material, according to the mix, for the production of 1 m³ of concrete is given in Table 8. The amounts of cement, gravel and water do not vary according to the mix, because the replacement is only the fine aggregate by kaolin waste.

Table 8 - Consumption of each material per m³ of concrete.

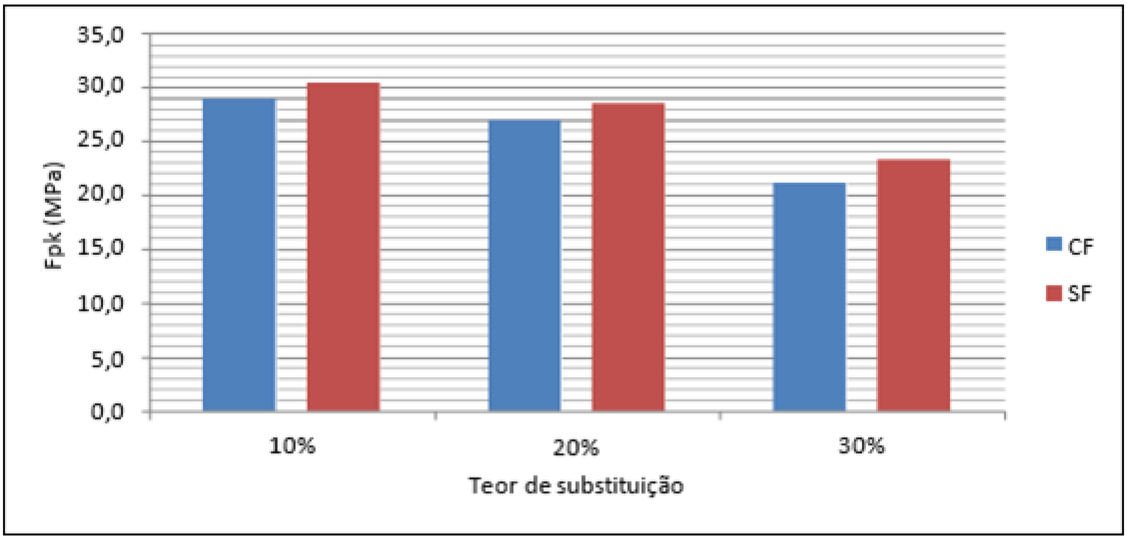
Trace	Materiais (kg)				
	Cement	Fine aggregate	Coarse aggregate	Water	Residue
Conventional	375	664	1038,5	225	0
10% Caulim	375	597,6	1038,5	225	66,4
20% Caulim	375	531,2	1038,5	225	132,8
30% Caulim	375	464,8	1038,5	225	199,2

Source: Souza, 2019.

3.3 COMPRESSIVE STRENGTH AT SEVEN DAYS

Figure 3 illustrates the characteristic compressive strength values of the pieces with increasing substitution content of each type of kaolin waste.

Figure 3 - Characteristic compressive strength of pavers at seven days.



Source: Souza, 2019.

According to the compressive strength test at seven days of curing, the mixtures that presented the best resistance were those containing 10% of fine aggregate replacement by waste. With this, the mixtures CF 10% and SF 10%, besides the conventional mix, were subjected to other physical and mechanical tests.

3.4 DIMENSIONAL EVALUATION

The molds used in the manufacture of the concrete pieces have larger dimensions on the lower face in relation to the upper face, in order to dispense with the use of spacers during the execution of the interlocked sidewalk. The actual dimensions of the pavers are described in table 9.

Table 9 - Dimensions of the pavers.

Piece	Thickness (mm)	Inferior Width (mm)	Superior Width (mm)	Inferior Length (mm)	Superior Length (mm)
Piece 1	60	99	94	197	193
Piece 2	59	99	95	197	193
Piece 3	60	99	95	197	192
Piece 4	60	99	94	197	193
Piece 5	61	99	95	197	193
Piece 6	61	99	95	197	193
Average	60	99	95	197	193

Source: Souza, 2019.

With the average values of the lower and upper dimensions, it was possible to find the average length and the average width of the pieces, in order to analyze if they are within the tolerances required by the standard. Thus, the average length was 195 mm and the average width was 97.

The actual dimensions of the parts are within the tolerances of ± 3 mm established by NBR 9781 (ABNT, 2013) in relation to the nominal dimensions of97 mm x 197 mm x 60 mm (width x length x thickness). In addition, the shape index is 2.03, less than 4, the length is less than 250 mm, the minimum thickness is 6 cm, and an 85 mm circle can be inscribed on its upper face, enabling it to be used in the compressive strength test.

3.5 WATER ABSORPTION

The water absorption test was performed on the pavers for the mixtures: conventional (CONV), 10% kaolin with fine (CF 10%) and 10% kaolin without fine (SF 10%) according to NBR 9781 (ABNT, 2013). The results obtained are presented in Table 10.

Table 10 - Water absorption of pavers.

Trace	Piece	m1	m2	A (%)	A (%)
	1	2568	2659	3,54	
CON V	2	2514	2610	3,82	3,75
	3	2502	2599	3,88	
	1	2470	2599	5,22	
CF 10%	2	2580	2687	4,15	4,79
	3	2518	2644	5,00	
	1	2542	2676	5,27	
SF 10%	2	2536	2662	4,97	5,10
	3	2528	2656	5,06	

Source: Souza, 2019.

According to the absorption results, both conventional concrete and concrete with 10% replacement of fine aggregate by waste with and without fines showed average absorption values less than 6% and individual values less than 7%. Thus, the concretes met the specifications of NBR 9781 (ABNT, 2013), allowing the replacement of 10% of the natural fine aggregate by kaolin waste.

The small variation between the absorption values of concretes CF10% and SF10% may be due to some small difference in the compaction process, since there were no significant changes between their granulometric compositions. A good densification of the mixture is determinant for a lower water absorption capacity of the concrete pieces, since it provides less porosity in the concrete, reducing the spaces responsible for water retention in the piece.

3.6 CHARACTERISTIC COMPRESSIVE STRENGTH

Table 11 shows the results of compressive strength at seven days of curing of conventional mixtures and with substitutions of 10%, 20% and 30% of fine aggregate by kaolin waste without fine (SF) and with fine (CF).

Table 11 - Characteristic compressive strength of pavers at seven days.

Trace		**Average Strength (MPa)**	**s**	**Characteristic compressive strength (MPa)**
CONV		38,60	0,1056	38,50
CF	10%	29,49	0,5280	29,01
	20%	27,10	0,1056	27,01
	30%	21,55	0,3758	21,21
SF	10%	31,26	0,8224	30,50
	20%	30,84	2,4286	28,60
	30%	24,24	0,9716	23,35

Source: Souza, 2019.

According to the results, the use of kaolin waste as aggregate in concrete resulted in a decrease in the characteristic strength of the pieces when compared to conventional concrete. The low strength of the tailings may be the cause of this change in behavior, not presenting the same characteristics of natural aggregates (sand and stone powder), explaining the continued decrease in strength with increasing use of the waste. The conventional concrete with seven days of curing showed a strength higher than 35 MPa, and can now be used in interlocking sidewalk with light vehicles and pedestrians, as specified in NBR 9781 (ABNT, 2013).

It is possible to analyze that the mixtures with the use of kaolin waste with fines showed lower strengths compared to the mixtures with kaolin waste without fines. The presence of this material with size less than 0.075 mm in the waste composition possibly caused a higher water absorption, reducing the water required for cement hydration.

In addition to the conventional mix, the mixtures with the waste that presented the best resistance at seven days (10% CF and 10% SF) were subjected to the compressive strength test at 28 days. Table 12 shows the values of the characteristic compressive strength of the pieces at 28 days of curing.

Table 12 - Characteristic compressive strength of pavers at 28 days.

Trace	Average Strength (MPa)	s	Characteristic compressive strength (MPa)
CONV	43,5	1,9489	41,71
CF 10%	37,93	1,8711	36,21
SF 10%	41,14	4,1181	37,35

Source: Souza, 2019

3.7 ABRASION RESISTANCE

Table 13 shows the results of the abrasion resistance of the pavers. The calibration value obtained from the abrasion equipment was 16.5, obtaining a calibration factor of 0.5 according to NBR 9781 (ABNT, 2013).

Table 13 - Abrasion resistance of pavers.

Trace	Cavity (mm)	Average Cavity (mm)
CONV	8,41 8,44 8,38	8,4
CF10%	7,88 9,57 9,54	9
SF10%	6,61 7,62 7,1	7,1

Source: Souza, 2019.

The results presented are well below the maximum cavity values determined by the standard, which are 23 mm for light traffic and 20 mm for heavy traffic, attesting to an excellent resistance to abrasion of the pavers both for the conventional mix and for the mixes using kaolin waste.

4 CONCLUSION

According to the characterization of the materials, the aggregates presented granulometric curves within the limits established by NBR 7211 (ABNT, 2013), attesting to the feasibility of using them as aggregates for concrete production. With the increase of the substitution content of natural aggregate for the residue, in the proportions of 10%, 20% and 30%, there was a reduction in the compressive strength of the pieces with seven days of curing. Thus, the mixture with 10% of substitution presented, among those with kaolin waste in its constitution, the best value of compressive strength at early ages.

The pieces with 10% kaolin with fines and without fines presented, at 28 days, compressive strengths higher than 35 MPa, the minimum value according to NBR 9781 (ABNT, 2013) for pedestrian and light vehicles, but still with lower values than conventional concrete. In addition, the mixtures using the waste without fines obtained higher strength than the concrete using the waste with fines.

Regarding the flexural tensile strength test, the pieces showed very satisfactory strength values, meeting the minimum values required by international standards, cited by some Souzaes, for application in sidewalks with heavy loads.

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