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Tactile-floor tile hydraulic with addition residue improvement dimension stones

Ladrilho hidráulico piso tátil com adição de resíduo de beneficiamento de rochas ornamentais

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Abstract

The hydraulic tile is a cement material produced in a handmade way, pressed, composed by three layers. With the coming of sidewalks adaptation in accessibility patterns, the tactile-floor tile hydraulic was developed to constitute the floor strip of alert for vision disabled people. The work has the objective to develop the mix design of the tile containing hydraulic binder with addition of granite residue. Properties analyzed: water absorption, rupture load, flexural modulus and wear by abrasion test. It was verified that the addition of residue to the tile, that it acted as a filler, promoted improvements in the analyzed properties; which makes the addition of granite residue an alternative technically feasible for the use in sidewalks and also a contribution to the sustainable development of the sector of granite improvement.

Keywords: tactile-floor tile hydraulic, residue improvement dimension stone, accessibility, sustainability, recycling.

Resumo

O ladrilho hidráulico é um material cimentíceo produzido de forma artesanal, prensado, composto de três camadas. Com o advento da adaptação de calçadas em padrões de acessibilidade, foi desenvolvido o ladrilho hidráulico piso tátil para constituir a faixa de piso de alerta para deficientes visuais. O trabalho tem como objetivo desenvolver a dosagem do ladrilho contendo aglomerante hidráulico com adição de resíduo de granito. Foram analisadas as propriedades: absorção de água, carga de ruptura, módulo de resistência à flexão e a resistência ao desgaste por abrasão. Foi verificado que a adição do resíduo ao ladrilho, que agiu como um fíler, promoveu melhorias nas propriedades analisadas, o que faz com que a adição de resíduo de granito seja uma alternativa tecnicamente viável para uso em calçadas e contribua para o desenvolvimento sustentável do setor de beneficiamento de granito.

Palavras-chave: ladrilho hidráulico piso tátil, resíduo de beneficiamento de rochas ornamentais, acessibilidade, sustentabilidade, reciclagem.

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1. Introduction

The recent growth in demand for the use of tactile-floor hydraulic tile in pavement with accessibility standards in several Brazilian cities raised the problem of scarcity of scientific methods of mix design for the product in question, with only empirical studies made by craftsmen, which is due to the character of artisanal production of hydraulic tile [1, 2] (Figure 1). In that sense, the aim of this paper is to develop the mix design of tactile-floor hydraulic tile with addition of residue improvement granite, in order to make the tile a more sustainable building material on recycling the residue in question as a raw material in its manufacturing, and promote improvements in the properties of the tiles produced, which are evaluated according to parameters of Brazilian standards NBR 9457:1986 [3], NBR 9459:1986 [4] and NBR 9050:2004[5].

1.1 The use of residue improvement granite in the hydraulic tile

The activities of extraction and improvement of dimension stones are very important to the economic development of Brazil. In 2007, the sector totalized about 8.0 million tons produced, generating approximately 140000 direct jobs and 420000 indirect ones [6]. Concomitantly, it appears that the high production sector involves large amounts of residue generated, which corresponds to a percentage of 25% to 30% of the volume of the rock block in the process of sawing slabs [7, 8, 9]. The stone sector currently suffers retraction in production as a result of the global economic crisis and the extraction of slabs that add value to the product instead of stone blocks can be pointed to as an alternative to resumption of development of the mining sector, which has led to an increased waste generation and consequently to a greater concern on sustainability in the environmental aspect of the industry of dimension stones. Several researchers [10, 11, 12, 13, 14, 15, 16] claim that the residue, which is normally discarded by the industry can contaminate the environment and be harmful to human health when in powder form. And although there are several scientific researches on recycling of residue materials for construction presenting highly relevant results, the practical application is still small, which may be due to the culture of citizens and businesspeople, besides the government itself, for the absence of incentives.

Studies on the utilization of the residue improvement dimension stones in cement mortar and concrete screed support the maintenance or improvement in properties in fresh and hardened state of the products formed, such as increased compressive strength and density and decrease porosity, which helps to confirm the effect of “filler” promoted by the residue [17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28]. Therefore, using the residue improvement granite in tactile-floor hydraulic tile seeks to obtain an increase in the compactness and durability of the final product.

Figure 1 – Hydraulic tile and use in pavement

(a) Hydraulic tile

(b) Use in pavement

2. Methodology

Initially, the material components of hydraulic tile and the residue to be added into the formulation were characterized. Tile hydraulic factories in the state of Espirito Santo were visited in order to study the methodology for mix design of hydraulic tile, and from that point, the experimental study of mix design of tactile-floor hydraulic tile with added residue began, as well as the verification of properties of the hydraulic tiles obtained in LEMAC UFES.

3. Characterization of materials

The materials that make up the hydraulic tiles are divided into three layers, namely:

- top layer - composed of Portland cement CPIII40RS, residue, water and pigment Bayferrox 732;

Table 1 – Characterization of residue

Test	Standard	Result
Specific gravity	NBR NM 23:2001 (29)	2,770 g/cm^3
Specific area	NBR NM 76:1998 (30)	494,2 m^2/kg
Granulometry	NBR NM 248:2003 (31)	See Table 1

Table 2 – Particle size distribution of residue improvement granite

Sieve N°	(ABNT) # (mm)	Percent retained (%)	Cumulative percent retained (%)
50	0,300	4	4
100	0,150	3	7
200	0,075	10	17
325	0,044	10	27
fund	-	73	100
total		100	-

- intermediate layer - composed of cement CPIII40RS and residue;
- lower layer - composed of Portland cement CPIII40RS, natural sand deposit, residue and water.

The residue of improvement dimensions stone used was characterized in accordance with the procedures of the tests of Table 1 with their respective results.

The grain size distribution of the residue is presented in Table 2. It was found that the residue has 83% particles smaller than 0.075 mm, that is, it is a powdery material that should act as a filler, filling the gaps in cement materials and increasing their compactness.

The chemical characterization of residue is presented in Table 3. It was found on a chemical analysis that the residue contains high levels of silica (SiO_2) and alumina (Al_2O_3), showing the residue as a silica-aluminous material. The presence of calcium oxide and iron oxide (CaO and Fe_2O_3) is drawn primarily from lime and grit contained in the abrasive mud used in the process, as abrasive and lubricant, respectively. It was also noted the presence of sodium and potassium (K_2O and Na_2O), which are flux agents, derived from feldspar and mica present in the granite, stone that gives rise to the residue.

The mineralogy characterization of the residue is shown in Figure 2. In X-ray diffractograms, the following peaks that correspond to crystalline phases of the main minerals present in the residue were identified: quartz, microcline, albite, calcite and muscovite.

The environmental characterization of the residue obtained in leaching tests (NBR 10005:2004 [32]) and solubilization (NBR 10006:2004 [33]) classified the residue of dimension stones as non-dangerous (class II) and inert (B), in other words, it is a residue of class II-B.

The sand characterization is shown in Table 4 and Table 5.

Characterization of Portland cement CPIII-40RS used is shown in Table 6.

4. Mix design of tactile-floor hydraulic tile with addition of residue improvement dimension stones

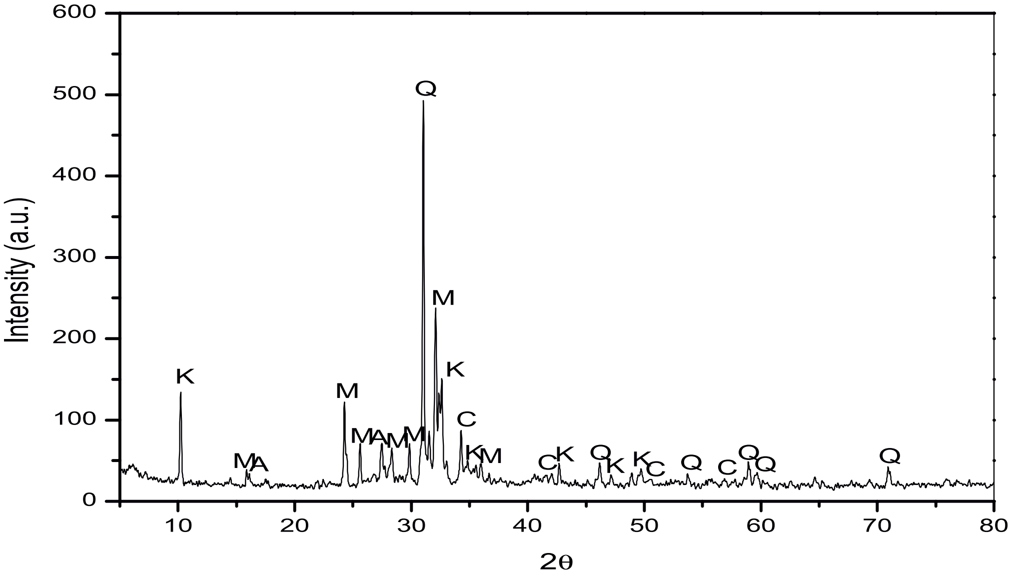
Due to the scant literature on methods of mix design the hydraulic material composition of the tile, it became necessary to visit factories of hydraulic tile in the state of Espírito Santo (which use empirical proportions in the mix design of the product) and studies on mix design, based on scientific methods of packing particles through particle size of materials and efficiency of compression. Such studies aim to obtain a product of high packing density and maximum compression in pressing particulate [44, 45], as the residue, for being a filler, must have a physical effect action of grain size packing in cement products [46, 47]. Thereafter, studies on mix design for the three layers of hydraulic tile were initiated, separately, to attend the NBR9457: 1986 [3], which states the product to be produced in three distinct layers. In each study of the mix design of the layers, tactile-floor hydraulic tile were moulded in semi-industrial hydraulic press with pressure ranging from 200 kgf/cm² to 250 kgf/cm² (Figure 3).

After pressing, the hydraulic tile remained outdoors for 24 hours, and then, the immersed cure was proceded in a moist chamber for 7 days. After this period, the tile remained outdoors until 28 days for verification tests of the hydraulic tiles properties during the studies done. Such check aimed to analyze the influence of the residue

Table 3 – Elemental composition of the sample of residue improvement granite (% mass) expressed as oxides

Elemental composition expressed as oxides	Concentration (%)
SiO_2	59,37
Al_2O_3	13,50
CaO	7,88
Fe_2O_3	6,52
K_2O	4,83
Na_2O	2,90
MgO	1,08
TiO_2	0,61
P_2O_5	0,54
BaO	0,18
MnO	0,09
SO_3	0,09
SrO	0,05
ZrO_2	0,05
Cl	0,04
Rb_2O	0,02
Loss Ignition	2,24
	100,00

Figure 2 – Mining analysis of residue improvement dimension stones



and the limits attendance prescribed by the NBR 9457:1986 [3], which are presented in Table 7.

4.1 Mix design study on the top layer of hydraulic tile

The paste that forms the top layer should be spread in the mould and flow into the intermediate layer so that it does not make the tile demolding difficult after hydraulic pressing, making it necessary to study the flow of the layer. The paste must have good workability and cohesion and this depends on the proportion of fine particles in the formulation, which leads to the study of various mix design ratios to obtain proper cohesion [46]. Therefore, the residue was added in the concentrations 0%, 10%, 20%, 30% and 40% compared to the cement mass and the mini slump and Marsh funnel essays were performed. The test procedures of mini slump followed the Gomes methodology [50]. The trial aims to study the behaviour of pastes with mineral admixtures [51], and so, find the optimum mix design of the relationship between fine and cement. The test for determining the flowing index of the folder by the Marsh funnel followed NBR 7682:1983 [52], in which the flowability index is the measure of time in seconds, 1000 cm^3 paste takes to drain the Marsh funnel. The density of the paste was also determined.

4.2 Mix design study on the lower layer of hydraulic tile

Preliminary tests were performed for manufacturing hydraulic tiles to establish a procedure for production and to obtain an initial mix design of hydraulic tile that caused them to be demolded without breaks, being adopted 1:3 (cement:dry material) mix design for the lower layer and 1:2 (cement:residue) mix design for intermediate layer, both in mass. The study of the lower layer was anticipated in relation to the study of the intermediate layer, as it was verified in preliminary tests that it influences, more directly, the properties of hydraulic tile, such as water absorption and flexural strength modulus.

Table 4 – Characterization of sand

Test	Standard	Result
Specific mass	NBR NM 52:2003 (34)	2,63g/cm^3
Apparent specific gravity – state compact Index of emptiness (Ev)	NBR NM 45:2006-Method A (35)	1,56 Kg/dm^3 40,68%
Apparent specific gravity – loose state Index of emptiness (Ev)	NBR NM 45:2006-Method C (35)	1,48 Kg/dm^3 43,73%
Powdery materials rate	NBR NM 46:2003 (36)	0,43%
Lumps of clay	NBR 7218:1987 (37)	There´s none
Average coefficient of swelling	NBR 6467:1987 (38)	1,31
Granulometry	NBR NM 248:2003 (31)	See table 2

Table 5 – Particle size distribution of sand

Sieve N°	(ABNT) # (mm)	Percent retained (%)	Cumulative percent retained (%)
4	4,800	0	0
8	2,400	2	2
16	1,200	16	18
30	0,600	40	58
50	0,300	31	89
100	0,150	9	98
200	0,075	2	100
total		100	-

Table 6 – Characterization of cement Portland

Test	Standard	Result
Water for normal consistency paste	NBR NM 43:2003 (39)	31,0%
Blainespecific surface	NBR NM 76:1998 (30)	4000 cm^2/g
Initial setting time	NBR NM 65:2003 (40)	250 minutes
Final setting time		300 minutes
Specific mass	NBR NM 23:2001 (29)	2,98 g/cm^3
Fineness na #200	NBR 11579:1991 (41)	0,1%
Strength compressive	NBR 7215:1996 (42)	3 days – 17 MPa 7 days – 30 MPa 28 days – 45 MPa
Expansibility Le Chatelier	NBR 11582:1991 (43)	0,5 mm

Study on the packing of grains in the lower layer of the tactile-floor hydraulic tile was conducted through analysis of the particle size distribution of sand and residue, because the residue, for presenting smaller particles than those present in the sand used, must improve the packing of the grains in the formulation, which was verified by Neville (1997) [46]. The model applied was ALFRED, described in Oliveira et al. (2000) [44]. The calculation of CPFT (Equation 1), which consists on establishing a cumulative percentage of particles smaller than a certain size (D_p), was based on the assumption that the smallest particle diameter (D_s) of the residue, which is a filler , measures 1 μm (0.001 mm) and the diameter of the largest particle (D_L) of sand measures 4.80 mm. Adopting q = 0.37 of the model, where:

$$CPFT = \left[\frac{D_p^q - D_s^q}{D_L^q - D_s^q} \right] x\ 100\ (\%) \qquad (1)$$

Considering the particle size distribution analysis of the residue and sand, which showed respectively 93% and 2% of particles located below the sieve # 0.150 mm and by calculating the CPFT, it was noticed that 24.5% of particles smaller than 0.150 mm could be

Figure 3 – Hydraulic press

Table 7 – Tests performed and Limits of NBR9457:1986 (3)

Properties	Standard	Limits NBR9457:1986 (3)
Water absorption	NBR13818:1997 Annex B (48)	≤ 8%
Strength of wear by abrasion	NBR12042:1992 (49)	≤ 3 mm in 1000m
Flexural strength modulus (FSM)	NBR13818:1997 Annex C (48)	Average value 5 MPa Minor unit value 4,6 MPa
Tickness	NBR13818:1997 Annex S (48)	± 10%
Length and width	Assessment dimensional	± 0,2%

supplemented by the residual particles, resulting on the increase of the residue amount in relation to the total mass of sand residue of 4.5% and an increase of 3.3% in the amount of residue in dry weight of the layer.

The analysis of the compaction of particles was done through the compression test, following standard NBR12023: 1992 - Soil-cement - Method A [53]. A dry mixture of the components of the lower layer of the tactile-floor hydraulic tile was made to study the water content which would lead to the value of the maximum dry density. To simulate the compaction energy used in hydraulic tile during pressing, adjustments were provided, such as: the number of strokes was 63 in each of the three layers, use of large socket (4.536 kgf), drop height of the socket 45,7cm and use of drum pattern. Then the ratio w/c ideal for maximum compression of the layer was obtained.

From the results, hydraulic tiles were molded in mix designs 1:3, 1:2 and 1:1 in mass, in order to obtain the highest granulometric packing possible between the residue and the sand and also to verify the influence of increased amounts of Portland cement in the values of flexural strength obtained.

4.3 *Mix design study on the intermediate layer of the hydraulic tile*

It was initially adopted the mix design 1:3 (cement: residue) mass, changing the ratio of residue to 1:2 and 1:4. Hydraulic tiles were molded with the three mix designs levels and the properties were checked. Mix designs in the lower layer were maintained at 1:2. in this study.

4.4 *Study on the final mix design of hydraulic tile*

Final mix design was adopted for the hydraulic tile from the test results of water absorption and flexural strength. Hydraulic tiles were molded in the final mix design for dimensional evaluation and verification of strength to wear by abrasion of the floor.

4.5 *Evaluation of dimensional hydraulic tile*

The test for dimensional evaluation in hydraulic tiles was performed according to NBR 13818:1997 - Annex S [48], and was conducted at the UFES Metrology Laboratory, in the equipment called Counterpoints Support Mark C. Stiefelmayer KG. It was done to determine the length, the straightness of sides, the orthogonality of the sides, the central curvature, the lateral curvature and the buckling. The test results were expressed in the form of percentage deviations, through Equations 2, 3, 4, 5 and 6 (Table 8). Some parameters in the test are shown in Figure 4.

4.6 *Strength to wear by abrasion of hydraulic tile*

The test for determination of the strength to wear by abrasion, which followed the NBR12042:1992, was held in hydraulic tiles manufactured in the final mix design at 28 days of age.

5. *Results and discussion*

The results of the verification of the properties of tactile-floor hydraulic tile produced by the survey are presented below.

5.1 *Result of the mix design study on the top layer of the tile hydraulic*

The test results are presented in Table 9.

Table 8 – Equations percentage deviations from dimensional assessment

$$\text{Percentage deviation from orthogonality of the sides} = \frac{\Delta\ell_1}{\text{W (corresponding side)}} \times 100 \quad (2)$$

$$\text{Percentage deviation from straightness of the sides} = \frac{\Delta\ell_2}{\text{W (corresponding side)}} \times 100 \quad (3)$$

$$\text{Percentage deviation from central curvature} = \frac{\Delta\ell_3}{\text{De}} \times 100 \quad (4)$$

$$\text{Percentage deviation from lateral curvature} = \frac{\Delta\ell_4}{\text{W (corresponding side)}} \times 100 \quad (5)$$

$$\text{Percentage deviation frombuckling} = \frac{\Delta\ell_5}{\text{De}} \times 100 \quad (6)$$

Figure 4 – Details of the test evaluation dimensional

(a) Orthogonality of side

(b) Distortion of floor

Table 9 – Test results of mini slump, the Marsh funnel and the attainment of the upper layer density

Residue content (%)	w/c	Mini slump (mm)	Marsh funnel (s)	Density (Kg/m^3)
0	0,70	111,41	14	1,630
10	0,70	102,44	39	1,652
20	0,70	85,23	134	1,676
30	0,70	68,67	1208,4	1,713
40	0,70	64,22	n.d.	1,756

Note: n.d. flow time not determined

The flow of paste in the Marsh funnel became discontinuous with a content of 40% residue. The difficulty on conducting the trial had already been noticed when the addition of residue was 30%. These facts are consistent with Calmon et al. (2005) [26], who verified that the pastes with scattering in the final test of mini slump below 70 mm did not flow into the Marsh Funnel. The test results led to a level of 20% waste in the upper layer of hydraulic tile. The dosage of the top layer is shown in Table 10.

Table 10 – Mix design of the top layer (mass)

Mix design	cement	pigment	residue	water
Top layer	1	0,03	0,20	0,70

5.2 Result of the mix design study on the lower layer of hydraulic tile

In the study of packing in the grain size distribution the increase of the amount of residue was obtained (Table 11). The properties of hydraulic tiles were studied at the mix design 1:3 with the residue of 15% and 18.3% (obtained in the study) in dry mass of the layer (Table 12). The modulus of flexural strength met the provisions of the standard average NBR9457: 1986 [3], while the water absorption, despite suffering decline in value, did not reach the standard.

In the study of the compaction of particles the optimum water content of 7.5% was obtained, which represents the ratio w/c = 0.30, and thus, hydraulic tiles were molded and evaluated for their properties according to Table 13.

It was found that there was no improvement in property values of tactile-floor hydraulic tile molded with water content obtained from compaction tests, when compared to values obtained on the packing. The ratio w/c obtained in the compression test was not enough

Table 11 – Mix designs of study on packing of lower layer (mass)

Mix design	cement	sand	residue	water	Residue content (%)
1:3	1	2,4	0,60	0,35	15
	1	2,27	0,73	0,35	18,3

Table 12 – Results of the study on packing in the lower layer of the tactile-floor hydraulic tile

Mix design					Water absorption (%)			FSM (MPa)		
(mass)	cement	sand	residue	water	n° s.	Average	S.D.	n° s.	Average	S.D.
1:3	1	2,4	0,6	0,35	5	14,97	0,45	5	4,41	0,65
	1	2,27	0,73	0,35	3	12,99	1,25	3	5,16	1,30

Note: FSM = flexural strength modulus; s. = specimen; S.D. = standard deviation.

Table 13 – Result of study on compacting in the lower layer of the tactile-floor hydraulic tile

Mix design					Water absorption (%)			FSM (MPa)		
(mass)	cement	sand	residue	water	n° s.	Average	S.D.	n° s.	Average	S.D.
1:3	1	2,27	0,73	0,30	3	14,26	0,45	3	4,08	0,11

Note: FSM = flexural strength modulus; s. = specimen; S.D. = standard deviation.

Table 14 – Result of the study on mix designs 1:1, 1:2 e 1:3 in the lower layer of the tactile-floor hydraulic tile

Mix design					Water absorption (%)			FSM (MPa)		
(mass)	cement	sand	residue	water	n° s.	Average	S.D.	n° s.	Average	S.D.
1:1	1	0,75	0,25	0,20	3	16,25	0,23	3	6,62	0,52
1:2	1	1,6		0,20	3	13,06	0,70	3	6,23	0,28
1:3	1	2,27	0,73	0,35	3	12,99	1,25	3	5,16	1,3

Note: FSM = flexural strength modulus; s. = specimen; S.D. = standard deviation.

Table 15 – Result of the study on the intermediate layer of tactile-floor hydraulic tile

Mix design	Water absorption (%)			FSM (MPa)		
(mass)	n° s.	Average	S.D.	n° s.	Average	S.D.
1:2	3	13,51	0,14	3	5,43	0,19
1:3	3	13,06	0,7	3	6,23	0,28
1:4	3	14,02	0,12	3	5,04	0,25

Note: FSM = flexural strength modulus; s. = specimen; S.D. = standard deviation.

to lubricate and facilitate the accommodation of grain t o improve the compactness of the tile with the hydraulic press used.

Mix designs for improving the flexural strength and results are presented in Table 14.

It was found that the mix design received 1:2 high value of flexural strength for a considerable recovery of residue. It was also considered that the mix design was very close to 1:3 limit standard and mix design 1:1 showed higher absorption.

5.3 Result of the mix design study on the intermediate layer of the tile hydraulic

The test results in the intermediate layer are presented in Table 15.

It was verified in the results of tests for determining the modulus of flexural strength and water absorption that the mix design 1:3 had better results in the intermediate layer.

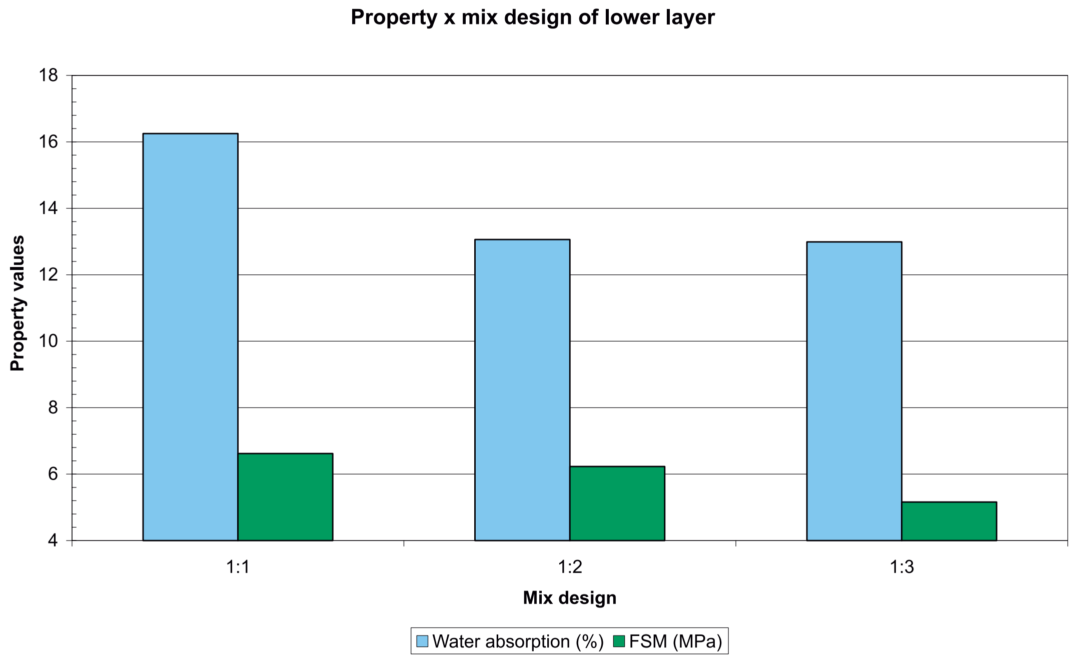
5.4 Water absorption and flexural strength modulus

Figure 5 shows the values found in the tests of water absorption and flexural strength modulus of the three dosages 1:1, 1:2 and 1:3 in the lower layer.

The flexural strength modulus met the provisions of the standard average NBR9457: 1986 [3].

As for water absorption, the 8% of the standard was not met. However, NBR9457: 1986 [3] specifies that the lower layer of hydraulic tile must

Figure 5 – Values of water absorption and flexural strength modulus (FSM) x mix design of lower layer



be formed of porous material, and encourage adherence. As porosity is a measure of the proportion of the total volume occupied by the pores of the concrete, and the absorption is measured by the volume of the pores [46] one may conclude that the tactile-floor hydraulic tile, which has less porous surface layer, will have a content of high water absorption, a fact also verified by Cavalli and Valduga (2006) [1].

5.5 Result of the final mix design of hydraulic tile tactile floor with residue

The final mix design is given in Table 16.

5.6 Result of the dimensional evaluation

The analysis of acceptability of the assessment was based on the dimensional values of NBR 13818:1997 [48] Annex T - Frame IX - Group Absorption BIIb (pressed) with water absorption (WA) in the range: 6% < WA < 10% with surface (S) product between 190cm² and 410cm². Such analysis is presented in Table 17.

According to the values found in the dimensional test evaluation, tactile-floor hydraulic tile manufactured in this research meets the limits of the standard.

5.7 Result of determination of strength to wear by abrasion

The result is shown in Table 18.

It was found that the hydraulic tile disregarded the wear limit of the standard, which is due to the fact that the product presents a high ratio w/c in the surface layer, which is not conducive to good density, and thereby, the compressive strength and the strength to wear by abrasion of the floor are decreased [46].

6. Conclusions

Based on the experimental development and on the results obtained, we may conclude that the addition of the residue from improvement dimension stones in tactile-floor hydraulic tile increased the flexural strength of the product, which was above the limit specified in the NBR 9457:1986 [3], thus, confirming its "filler" effect in cement materials.

The dimensional evaluation met all the parameters of NBR 9459:1986 [4], which means that the geometric properties of the mold made are appropriate.

Water absorption showed results of at least 13%, which disregarded the value of 8% of the Standard. This is explained by the fact that the hydraulic tile has a lower layer porous to facilitate its adhesion to the substrate. Durability tests should be conducted to verify the influence of water absorption in order to propose, if necessary, study changes in the rate of absorption in NBR9457: 1986 [3]. According to REIS (2008) [2] it can be seen that the hydraulic tiles sold in the region of the State of Espirito Santo, which contain no

Table 16 – Final mix design (mass)

Final mix design					
Layers	cement	sand	residue	water	pigment
top	1	0	0,2	0,70	0,03
intermediate	1	-	3	0	0
lower	1	1,6	0,4	0,20	0

Table 17 – Result of the dimensional evaluation tactile-floor hydraulic tile

Geometric properties	Unit	Limits NBR13818:1997(48)	Values
Deviation **r** in relation to **W**	%	± 0,75	0,06
Deviation **r** in relation to **R**	%	± 0,5	0,15
Deviation **e** in relation to **ew**	%	± 5,0	3,05
Straightness of sides - ΔL5	%	± 0,5	-0,15
Orthogonality - ΔL1	%	± 0,6	0,17
Central curvature - ΔL3	%	± 0,5	-0,35
Lateral curvature - ΔL4	%	± 0,5	0,23
Buckling - ΔL2	%	± 0,5	0,21

Note: r = average of the 4 sides of the hydraulic tile; R = average side of the sample group; e = thickness of the hydraulic; ew = thickness of reference.

Table 18 – Result of strength of wear by abrasion of tactile-floor hydraulic tile

Wear (mm) after 1000m		
Result	NBR limit	S.D.
8,92	< 3	0,63

Note: S.D.= standard deviation

residues, do not meet the prescribed values of absorption either. The strength of wear by abrasion was not answered, because it is a floor in which the surface layer has a high water cement ratio (w/c = 0.70), which is inherent in the manufacturing process to get the paste to flow into the mold, obtaining perfect surface finish on the product, besides allowing the demolding without breaks. New mix design studies in the surface layer must be done with the use of additives plasticizers to decrease the ratio w/c, without damages to the workability of the paste. This measure should encourage the increase of the strength of wear by abrasion of the floor.

In this sense, there is a need for further research as for the results obtained for water absorption and strength of wear by abrasion of the floor. It is important to emphasize that this study begins a discussion of methods for mix design for the hydraulic tile, now back in use, to improve the technical properties and also starts a discussion of the parameters applied to the standard product.

Through this research, one can reaffirm that the recycling of solid residue generated in the sector of dimension stones is one of the alternatives to make the industry sustainable in the environmental aspect, as it causes a decrease in the volume of landfill and possible contamination of soil and water, besides the addition of the residue allows minor consumption of non-renewable natural materials in the manufacture of new products.

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8. References

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