PROPOSAL OF A MODEL FOR ESTIMATING THE USEFUL LIFE OF GLAZED CERAMIC TILES SUBJECT TO ABRASIVE WEAR

Ana Luiza Raabe Abitante(1),
Carlos Pérez Bergmann(2),
José Luis Duarte Ribeiro(3)

(1)Universidade Federal do Rio Grande do Sul
UFRGS, Núcleo Orientado para Inovação da Edificação – NORIE. Brazil.
(2)Universidade Federal do Rio Grande do Sul
UFRGS, Laboratório de Materiais Cerâmicos – LACER. Brazil.
(3)Universidade Federal do Rio Grande do Sul
UFRGS, Lab. de Otimização de Produtos e de Processos - LOPP. Brazil.

ABSTRACT

The present study proposes a model for estimating the useful life of glazed ceramic tiles subject to abrasion. The work is based on a comparative study between the behaviour found through accelerated tests, with a specifically developed abrasion apparatus, and the field behaviour resulting from the exposure of ceramic tiles to real conditions of use, subjected to pedestrian traffic. As wear evaluation parameters, variables were adopted related to the appearance of the material: colour, gloss and mean roughness, Ra. To establish colour and gloss, a spectrophotometer was used, in addition to an observation chamber, in accordance with the standards established by standard test methods ASTM D 1729 and ASTM D 4449, respectively. The field study was conducted in a fast food restaurant, whose floor tiles, next to the access doors, displayed strong signs of wear. In the premises, the traffic was counted and the trajectories were identified that the people tended to follow to enter the establishment. Together with the historical data related to the consumption and population profile, it was possible to calculate the traffic that took place in each identified trajectory. The field measurements were performed by subdividing each ceramic tile in 25 regions, so that the results corresponded to the averages of the points that made up a given trajectory. The study analyses two types of movement: restrained and free movement. For the tests in the laboratory, samples were cut from a ceramic tile that had not been used, which was identical and from the same lot as that of the floor tiles in the restaurant flooring. The abrasive load and the abrasive concentration were adopted as experimental variables. The abrasive consisted of quartz flour in suspension, with 2% Sodium Silicate as a dispersant. In accordance with the project programme, the variables were split in 5 levels: 5N, 10N, 15N, 20N and 25N for the load, and 5%, 10%, 15%, 20% and 25% for the abrasive concentration. The condition found in the field was associated with the 25N load and 15% abrasive concentration. The test times were set at 4, 14, 45, 90, 145 and 356 minutes.

The modelling of the results was performed through SPSS software. The definition of the model that best represented the behaviour of the ceramic material, when subjected to the abrasion condition, was based on the exponents related to test time and pedestrian traffic. These revealed that the behaviour in the laboratory was similar to the wear generated in the field by the free movement condition, and that only the visual classification related to the observation of gloss has a coefficient determination > 0.5 and a relative error < 25%. Thus, from a statistical point of view, the visual classification based on gloss is the property with the lower margin of prediction error. Therefore, this characteristic must be considered the most appropriate one for estimating the service life of glazed ceramic tiles subject to abrasion. It was found that the variation of the appearance resulting from the abrasion test and the variation of the appearance resulting from pedestrian traffic, in free movement, were proportional, respectively, to the square root of time, expressed in minutes, and to the square root of the traffic, expressed in millions of people. Therefore, it is possible to establish an acceleration factor that enables estimating the future performance of this ceramic material, under real conditions of use.

1. INTRODUCTION

In accordance with standard ASTM E 632-82[4] (1996), the useful life of a material or component is the period of time, subsequent to installation, during which all the properties exceed the acceptable minimum values when the maintenance is routinely performed. Of course, one needs to discern among the properties of the tiles, those responsible for the functions of the tilings, which can be modified in time. In the case of ceramic flooring subject to pedestrian traffic, durability is conditioned by the preservation of visual appearance and safety in use[2]. The alteration of these properties means the end of useful life. The concepts of durability and useful life differ fundamentally in the way they view time. It may be said that useful life consists of the quantification of durability.

One of the methods of estimating the useful life of construction materials and components corresponds to the accelerated tests. ASTM E 632-82[4] (1996) establishes a procedure and provides recommendations that guide their development. Since one of the objectives of an accelerated test is to have data related to durability in a significantly smaller period of time than that evaluated in normal service conditions, this test must not distort the real phenomena of ageing. Yet it must still assure that the extreme levels adopted for these factors do not result in deterioration mechanisms that are not observed in real conditions. A deterioration factor consists of an external agent which unfavourably affects materials performance, including the effects of weathering, biological factors, loads, incompatibilities and factors of use.

In the experiments developed in the laboratory, the deterioration factors corresponded to the experimental variables. In this way, the development of the accelerated tests began by the definition of the test conditions. As a basic premise, there must be a correspondence between the wear mechanism caused by pedestrian traffic and the one caused in the accelerated mode, in the laboratory. This consistency is evaluated from the statistical parameters associated with the laboratory and field results. The relation between the alterations obtained through the accelerated tests and the alterations undergone in service conditions is represented by an acceleration factor.

2. FIELD STUDY

The field study consisted of the measurement of the variables that expressed the appearance of the material, designated response variables, in glazed ceramic tiles that displayed traces of wear, after a few years of use under pedestrian traffic.

2.1. CHARACTERISATION OF THE CONTEXT

The study premises correspond to a restaurant that serves light lunches, which opened in July 1993. The visually worn ceramic tiles were in the outside flooring access, at two of the three doors: at the main door and at one of the side doors, as depicted in figures 1 and 2. The tiles measure 295mmx295mm and are classified by the manufacturer as PEI V, in a sandy colour.

The wear, observed in the region immediately before the doors, is not perceivable in other premises in the same context. One assumes that this region shows conditions of high aggressiveness, since the doors do not open automatically and the people interrupt their free traffic movement to enter the establishment, which involves a restraining effect. At the same time, the doors are areas of traffic concentration, which disperses as soon as the persons enter the premises. This involves a dilution of the loading effect and of the amount of associated abrasive material, i.e. a reduction of the stresses. As pedestrian traffic causes two different effects, the study was structured to address these separately, as set out below:

- in relation to restrained traffic movement, whose wear action is considered through the tiles identified in figure 1 by coordinates 11, 12, 21 and 22, and in figure 2, by coordinates 31 and 32;
- in relation to free traffic movement, whose wear is evaluated through the tiles identified in figure 1 by coordinates -33, -23, 33 and 43, and in figure 2, by coordinates 24 and 15.

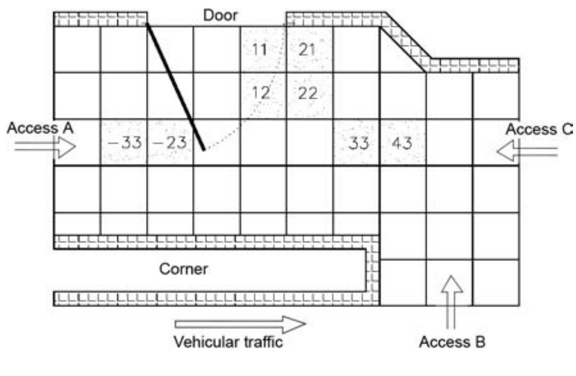

Figure 1. Position of the ceramic tiles next to the main door, in the external access to the restaurant.

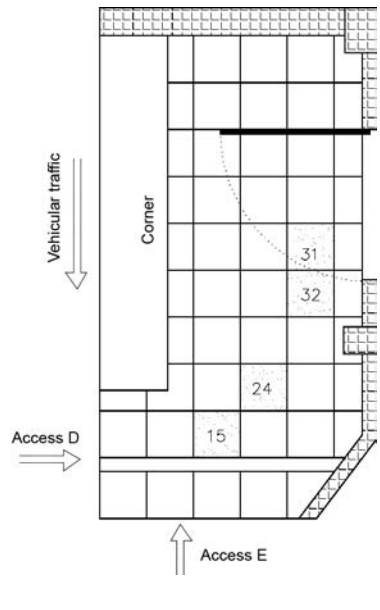

Figure 2. Position of the ceramic tiles next to the secondary door, in the external access to the restaurant.

2.2. IDENTIFICATION OF THE ROUTES

As the flooring that accesses the restaurant is approximately 1.40m wide, people can take different routes to reach the respective doors. Thus for each of the access directions, it was sought to identify the number of trajectories and parts of the tiles that ended up forming these preferential paths. This identification was performed by observation on the premises.

For the main door, as figure 3 shows, the people coming from access A tended to adopt 3 different routes, designated 1, 2 and 3. The front access tended to feature two trajectories, designated b' and b''. As expected, it was observed that the pedestrian steps did not exactly occupy the totality of each tile, but just well-defined parts of these. It can be observed that access C has quite a regular configuration. Figure 4 shows the travel configurations that the persons adopt, coming from accesses D and E, related to the secondary door.

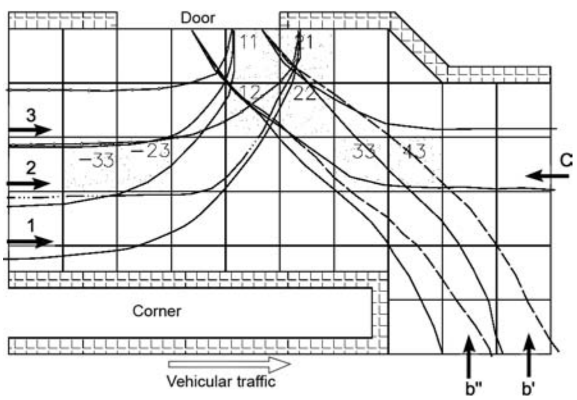

Figure 3. Preferential trajectories that lead to the main door of the restaurant

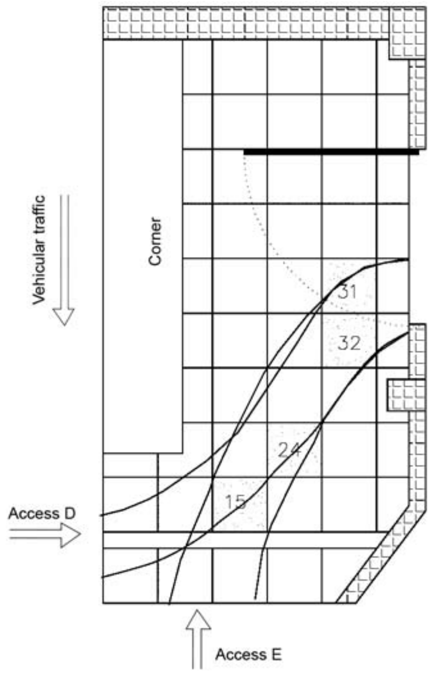

Figure 4. Preferential trajectories that lead to the secondary door of the restaurant

2.3. CORRESPONDENCE OF THE TRAJECTORIES WITH TILE SEGMENTS

Each ceramic tile was divided into 25 segments, performing the measurements in the centre of the resulting areas. The definition of this sample is based on standard ASTM D 523[3], in which a ceramic tile of 300x300 mm must have its properties quantified in, at least, 8 regions, each of which with three readings.

The identified trajectories were then associated graphically with the 25 segments that form each tile. As a result, the configurations were obtained that are plotted in figures 5 and 6, corresponding respectively to the restrained and free movement situations associated with the main door. When there was a superposition of b' and b'' traffic, the designation B is adopted.

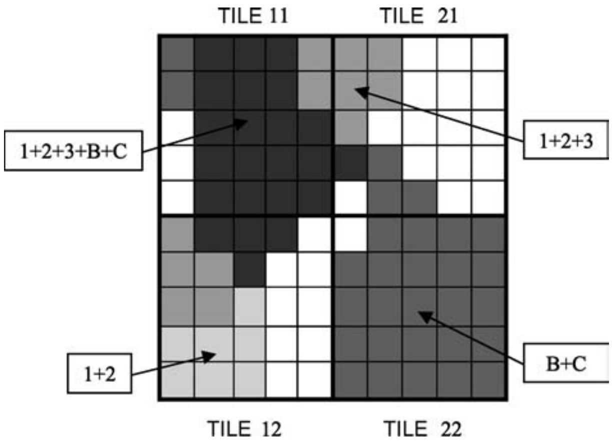

Figure 5. Segments of the ceramic tiles, subjected to restrained movement, associated with the trajectories in the main access

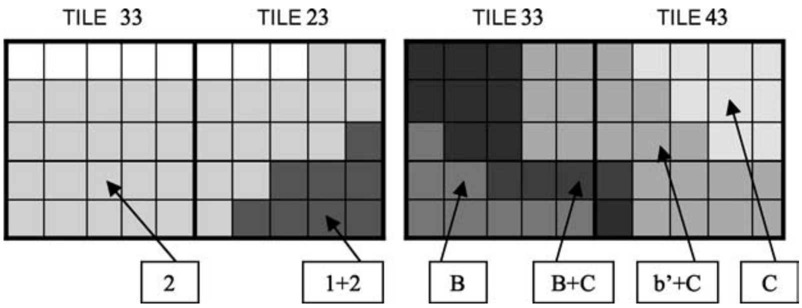

Figure 6. Segments of the ceramic tiles, subjected to free movement, next to the main door, associated with access A (left) and accesses B and C (right)

The segments without colour were not including in the study, because they received individually different trajectories, so that the set of these points does not form the same sum of traffic. In other situations, the white points are not part of a preferential path.

Figure 7 shows the segments associated with each trajectory related to the secondary door, for the free movement situations (on the left) and restrained movement (on the right).

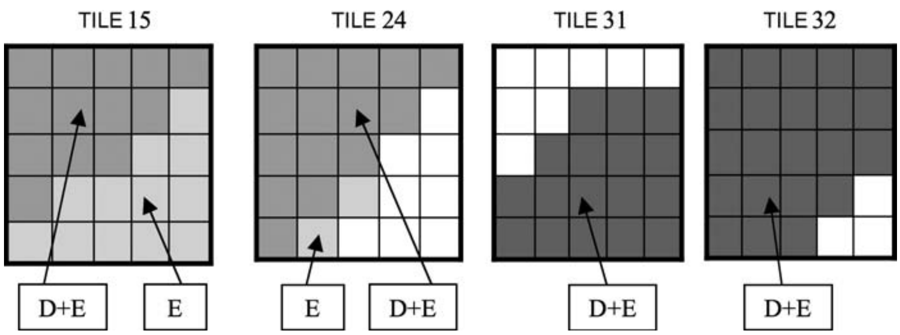

Figure 7. Segments of the ceramic tiles, subject to free movement (on the left) and to restrained movement (on the right) of the secondary door, associated with the D and E access trajectories.

2.4. DEFINITION OF THE PEDESTRIAN TRAFFIC

The definition of useful life normally takes into consideration the variable time. However, when floorings are concerned, time is not as representative as the number of people that cross the floor. Thus, it was sought to associate the segments, identified in the preceding point, with the number of persons. The number of persons was obtained from data provided by the company that runs the restaurant and by counting the traffic in the premises under study.

The calculation of the traffic was based on the number of *tickets* issued by the establishment, which were recorded by the company that runs the restaurant for the entire period of operation, except for the period between August 1993 and December 1994. For these months, the data were estimated from the extreme values, which corresponded to July 1993, the month the establishment was opened, and January 1995. The distribution was conceived as non-linear, respecting the variations inherent to every month, in accordance with the characteristics of the following years.

The transformation of the number of *tickets* into data on pedestrian traffic was based on statistical indices, calculated periodically by the company. Among these, to be noted is the number of people who entered the restaurant per order placed, the profile of the clients in terms of sex and age band, the consumption per hour and day of the week, the relation between the orders placed at the counter and in the *drive-thru*, the percentage of people that entered by the main door compared with the secondary doors.

The consumption through the *drive-thru* represents 40% of the total *tickets* and, across the counter accounted for 60 %. This last proportion includes the people who really crossed the floor and have three available access doors. Accordance to company data, 97% of the *tickets* issued across the counter corresponded to people who entered by the front door, and the others (3%) by the other two doors. The available data show that, up to December of 2000, 16,388,148 people passed through the main door and, up to November, 2002, 21,957,070 people had entered.

The traffic count needed to be performed because it was necessary to separate the percentage of 3%, corresponding to the two secondary doors, and also to identify the traffic associated with the public officials who added to the client traffic and, finally, the identification of the proportion of the traffic corresponding to accesses A, B and C, of the font door. The traffic count was conducted on weekdays, Wednesday and Thursday, with medium movement and in times of medium movement, from 16 hours till 20 hours. The assumptions made in the traffic count are set out below:

- all the people who enter by a door leave by the same one. The traffic is considered twice the number of people who enter;
- the traffic of the public cleaning and security officials is added to the movement of the clients; therefore, this movement is added to the client traffic by a percentage, determined in the traffic count.

The data shown in table 1 were calculated from the percentage identified in the traffic count for the different trajectories and the number of clients who came through the main door until 2000 and 2002. The quantification of the traffic, for two different years, was necessary as the field measurements on tiles 11, 12, 21 and 22 were made in December 2000, and the other measurements were performed in November 2002.

The traffic associated with the segments, shown in tables 2 and 3, were obtained by grouping the data displayed in table 1, according to the trajectories identified in the preceding point. With relation to the traffic of the public officials, it was observed that approximately 50% of these crossed along the outside of the establishment, without entering it, as part of the vigilance activities and external cleaning. Therefore, for the restraining effect, only the traffic of the other half of the officials is added to the client traffic.

DATA	ACCESS A						ACCESS B		ACCESS C		TOTAL CLIENTS	TOTAL OFFIC.	TOTAL PER-SONS
	ROUTE 1		ROUTE 2		ROUTE 3								
	CLIENTS	OFFIC.	CLIENTS	OFFIC.	CLIENTS	OFFIC.	CLIENTS	OFFIC.	CLIENTS	OFFIC.			
Total (pers/h)	34.80	9.76	44.15	11.65	12.07	1.33	72.45	9.26	21.16	18.27	184.62	50.27	
Total (%)	18.85	5.28	23.91	6.31	6.54	0.72	39.24	5.01	11.46	9.90	100.00	27.23	
Persons up to 2000	3,088,737	866,054	3,918,693	1,034,412	1,071,397	118,354	6,431,047	821,671	1,878,274	1,621,742	16,388,148	4,462,232	20,850,380
Persons up to 2002	4,138,333	1,160,351	5,250,319	1,385,919	1,435,473	158,572	8,616,407	1,100,886	2,516,538	2,172,833	21,957,070	5,978,561	27,935,631

Table 1. Estimated traffic corresponding to the front door accessing the restaurant

DATA	TRAFFIC, UP TO 2000, UNDER RESTRAINING EFFECT				TRAFFIC, UP TO 2002, UNDER FREE MOVEMENT EFFECT					
Trajectory	1+2	1+2+3	B+C	1+2+3+B+C	2	1+2	B	C	B+C	B'+C
Nº persons	7,957,662	9,088,237	9,531,028	18,619,264	6,636,239	11,934,922	9,717,293	4,689,371	14,406,664	6,632,829

Table 2. Estimated traffic, corresponding to the restrained and free movement trajectories, associated with the main door

The secondary door, besides receiving part of the client traffic, is characterised as a service door used by the officials in changing shifts, training and resting. This door also receives traffic associated with the delivery of order packages to the automobiles, by the officials. This situation happens when there are no packages for immediate delivery in the *drive-thru* or when there is an exaggerated build-up at peak, which causes an order overload. According to the information supplied by the company, such situations represent approximately 30% of the orders placed in the *drive-thru* system. However, the simultaneous delivery was frequently observed of two or three orders, in the same travel by the official. Thus, it was considered that the traffic related to the delivery of order packages consisted of 2/3 of the referred 30%. This traffic must still be multiplied by two to calculate the entry and exit of the officials. Table 3 contains the traffic for the secondary door, already associated with the trajectories.

DATA	TRAFFIC, UP TO 2002, UNDER THE EFFECT OF RESTRAINED AND FREE MOVEMENT	
Trajectories	E	D+E
Nº persons	3,213,579	3,746,317

Table 3. Estimated traffic corresponding to the trajectories of the secondary door

3. LABORATORY STUDY

The laboratory study consisted of subjecting samples to an abrasion test, cut from an unused ceramic tile identical to those in the restaurant flooring under study, pertaining to the same lot. The specimens were 40.5 ± 0.5mm wide and 55.0 ± 0.5mm long, disregarding, in the cutting, the outer 20mm of each side of the original tile.

The abrasion equipment used was specifically developed for the study, and is described elsewhere in Abitante et al.[2]. Quartz flour was used as abrasive material in a suspension with Sodium Silicate in a proportion of 2% as a dispersant.

The selection of the variables to be contemplated in the laboratory study[1] was based on the technique known as Research among Specialists, which considers the opinions of professionals for the selection of variables or the formulation of hypothesis. These persons use their pre-existing knowledge and establish a hierarchy, among the variables involved in accordance with the influence they have on a given phenomenon. Of the variables that define the tribological system related to pedestrian traffic, it was sought to determine which were the most influential in relation to the perception of abrasion. As a result the following variables were selected:

- gloss, colour and cleaning related to the ceramic material;
- load, related to the body in movement and;
- abrasive concentration, relating to the intermediate material.

In the present study, as the ceramic tile was not present as a variable, because it corresponded to the one defined in the field study, the variables to be used in the test consisted of the load and the abrasive concentration. To define these, the profile was characterised of the population of public officials and clients who frequented the establishment and the material was characterised, present in particle form, found on the flooring. For this latter characterisation, the grain size and mineralogical composition were determined from samples gathered in three field collections, on dry days and after a period of at least three days without rain. The material was removed slowly, with a small-sized, soft bristle brush which enabled collecting the finest fractions.

According to the experimental programme realised[7], the load and abrasive concentration variables were split in 5 levels: 5N, 10N, 15N, 20N and 25N, and 5%, 10%, 15%, 20% and 25%, respectively. The condition of aggressiveness found in the field was associated with a load of 25N and an abrasive concentration of 15%. The test times were set at 4, 14, 45, 90, 145 and 356 minutes, which enabled reproducing the behaviour of the specimens satisfactorily.

4. RESPONSE VARIABLES

The response variables, through which it was sought to quantify the abrasion phenomenon, were associated with the characteristics and properties of the ceramic material involved in the wear perception. The approach, therefore, refers to the preservation of the appearance of the material. In regard to the appearance defined by colour, gloss and texture, the instrumental measurements were made by diffuse reflection, specular reflection and mean roughness, Ra. Colour was analysed through the reflection curve and also by Delta E. Also evaluated, visually, were the variations in colour and gloss based on the observation conditions defined by ASTM D 1729[5] and ASTM D 4449[6].

The reflection was obtained with a Minolta CM 508D spectrophotometer. The specular reflection was obtained from the differences associated with the curves with an included and excluded specular component. As an illuminant, CWF was used (F2 fluorescent). The mean roughness Ra was determined with a Mitutoyo Surftest 211 roughness meter, using the configuration of the DIN standard and 2.5mm *cut-off*. In each sample we performed 12 roughness measurements, where three measurements were distributed in each of the directions: 0º, 45º, 90º and 135º with the horizontal. In regard to the observation chamber, the illumination inside it was measured using an ISO-TECH ILM 350 lux meter positioned on the face of the sample. In the configuration for gloss observation at 20º, 980 lux was recorded, and at 60º, 1070 lux. In the configuration for colour observation, with the sample positioned at 45º in relation to the illuminant, 925 lux was recorded. As the equipment did not work on the entire surface, the visual analysis consisted of comparing the region that had undergone abrasive wear with the original region of the same tile.

The visual classes were distributed from *0 to 1*, where *0* corresponds to the original state and *1*, to the total deterioration of the surface. For the intermediate levels it was sought to attribute some values that could signal the classification of the samples, such that 0.1 represents the beginning of the perception; 0.3, beginning to consider the problem worrying and 0.5, beginning to consider the problem aesthetically intolerable. It may be observed that this scale is associated with the developed apparatus and can be used for any type of ceramic tile. The definition of the visual class of a given sample, worn by abrasion is the result of the visual comparison of this with the standard samples that make up the scale and are assigned numerical values.

5. RESULTS

For each of the response variables, the values corresponding to the original state have been obtained from the mean of 25 measurements performed on the segments that made up an unused tile. For the field wear condition, for each response variable, the number of people was related that corresponded to the same traffic, with the values obtained from the mean values of the measurements made in the corresponding segments, as detailed in tables 2 and 3. For example, for tile 15, in figure 7, the traffic E, of 3,213,579 people, is associated with the mean of the measurements made in the centre of the 12 bottom segments. For the field condition and for the laboratory condition the work was done in terms of the differences between the abraded and original states.

6. MODELLING

The modelling of the results was done with the aid of SPSS *software*. In regard to the laboratory tests, the models describe the behaviour of the material as a function of time (t) and in regard to behaviour in the field, the models are a function of the traffic (tr), for both the restrained and free movement situations.

Tables 4 to 8 present the numerical models that describe the behaviour of the experimental results. The models represent the laboratory and field situations in the restrained and free movement conditions. The statistical parameters include the coefficient of determination (R^2), the mean absolute error (*MAE*), the relative error (ER) and the significance (SIGN) of the model. The relative error is calculated by dividing the predicted error by the estimation of wear obtained in the mean time and traffic condition considering, respectively, 60 minutes and 6 million people. Note that the results referring to the visual classification (table 6) are related to the observation of gloss. The colour observation was disregarded, because few samples evidenced variation, and did not even allow establishing a significant visual classification.

RESULTS	MODEL	STATISTICAL PARAMETERS	
Laboratory	$\Delta Rd = 0.6051.t^{0.478}$	$R^2 = 0.652$	ER = 39.7%
		MAE = 2.06	SIGN = 0.000
Field: restrained	$\Delta Rd = 6.26.tr^{0.296}$	$R^2 = 0.580$	ER = 13.9%
		MAE = 1.48	SIGN = 0.000
Field: free movement	$\Delta Rd = 2.76.tr^{0.523}$	$R^2 = 0.787$	ER = 12.7%
		MAE = 0.89	SIGN = 0.000

Table 4. Models and statistical parameters that describe the behaviour of the diffuse reflection of the ceramic tiles, abraded in the laboratory and field

RESULTS	MODEL	STATISTICAL PARAMETERS	
Laboratory	$\Delta E = 1.62.t^{0.249}$	$R^2 = 0.729$	ER = 19.12%
		MAE = 0.86	SIGN = 0.000
Field: restrained	$\Delta E = 4.96.tr^{0.287}$	$R^2 = 0.526$	ER = 14.9%
		MAE = 1.24	SIGN = 0.000
Field: free movement	$\Delta E = 1.88.tr^{0.567}$	$R^2 = 0.757$	ER = 16.0%
		MAE = 0.83	SIGN = 0.000

Table 5. Models and statistical parameters that describe the behaviour of delta E of the ceramic tiles, abraded in the laboratory and field

RESULTS	MODEL	STATISTICAL PARAMETERS	
Laboratory	$\Delta vis = 0.0102.t^{0.6705}$	$R^2 = 0.953$	ER = 23.6%
		MAE = 0.04	SIGN = 0.000
Field: restrained	$\Delta vis = 0.381.tr^{0.348}$	$R^2 =0.795$	ER = 9.8%
		MAE = 0.07	SIGN = 0.000
Field: free movement	$\Delta vis = 0.234.tr^{0.468}$	$R^2 = 0.754$	ER = 14%
		MAE = 0.08	SIGN = 0.000

Table 6. Models and statistical parameters that describe the behaviour of the visual classification based on gloss of the ceramic tiles, abraded in the laboratory and field

RESULTS	MODEL	STATISTICAL PARAMETERS	
Laboratory	$\Delta Re = -0.0878.t^{0.7058}$	$R^2 = 0.872$	ER = 17.2%
		MAE = 0.27	SIGN = 0.000
Field: restrained	$\Delta Re = -0.8209.tr^{0.1099}$	$R^2 =0.695$	ER = 2.8%
		MAE = 0.03	SIGN = 0.000
Field: free movement	$\Delta Re = -0.433.tr^{0.390}$	$R^2 = 0.941$	ER = 4.6%
		MAE = 0.04	SIGN = 0.000

Table 7. Models and statistical parameters that describe the behaviour of the specular reflection of the ceramic tiles, abraded in the laboratory and field

RESULTS	MODEL	STATISTICAL PARAMETERS	
Laboratory	$\Delta Ra = -0.0648.t^{0.823}$	$R^2 = 0.839$	ER = 50.6%
		MAE = 0.96	SIGN = 0.000
Field: restrained	$\Delta Ra = -12.4.tr.^{0.0146}$	$R^2 = 0.0231$	ER = 3.0%
		MAE = 0.38	SIGN = 0.000
Field: free movement	$\Delta Ra = -8.274.tr^{0.21}$	$R^2 = 0.527$	ER = 8.3%
		MAE = 1.0	SIGN = 0.000

Table 8. Models and statistical parameters that describe the behaviour of the mean roughness Ra of the ceramic tiles, abraded in the laboratory and field

7. DEFINITION OF THE MODEL

The definition of the model that best represented the behaviour of the ceramic material, when subjected to the condition of abrasion, was based on the exponents related to test time and pedestrian traffic, respectively for the models that represented the laboratory and field situations. For the specular reflection and also for the mean roughness Ra, the exponents related to time do not show any similarity with the exponents related to traffic. This means that the behaviour in the field is not reproduced suitably in the laboratory and, therefore, neither of the two properties constitutes a good indicator of the behaviour of ceramic tiles when subjected to an abrasive process. In addition, for both properties, the restrained and free movement curves, obtained from these models, show a reversal of behaviour beyond a given traffic, which should not happen in real conditions.

Table 9 shows the values of the time and traffic exponents for the other variables: diffuse reflection, delta E and visual classification. In this table, it can be observed that the values relative to the restrained effect are quite close and yield a mean value of 0.31. For the free movement situation, a similar situation is also verified, where the mean exponent is 0.52. The exponents of time, associated with behaviour in the laboratory, display greater variability; however they still give a mean value of 0.47.

CONDITION	DELTA E	DIFF. REFL.	VISUAL CLASSIF.	MEAN
Laboratory	0.249	0.478	0.671	0.47
Restrained	0.287	0.296	0.348	0.31
Free mov.	0.567	0.523	0.468	0.52
Mean	0.368	0.43	0.50	0.43

Table 9. Original exponents of test time and pedestrian traffic

The mean exponents reveal that the behaviour in the laboratory has an affinity with the wear generated in the field by the free movement condition. If both conditions are fitted for an exponent equal to 0.5, this is equivalent to considering that wear advances proportionally to the square root of use (time or traffic). Table 10 shows the fitted models and the resulting statistical parameters.

RESULTS	VARIABLE	MODEL	STATISTICAL PARAMETERS	
Laboratory	Delta E	$\Delta E_l = 0.441.t^{0.5}$	$R^2 = 0.3054$ $MAE = 1.47$	ER = 43.2%
	Diffuse reflection	$\Delta Rd_l = 0.531.t^{0.5}$	$R^2 = 0.651$ $MAE = 2.09$	ER = 41.4%
	Visual classification	$\Delta vis_l = 0.025.t^{0.5}$	$R^2 = 0.912$ $MAE = 0.05$	ER = 23.7%
Field: free movement	Delta E	$\Delta E_{cl} = 2.17.tr^{0.5}$	$R^2 = 0.747$ $MAE = 0.83$	ER = 15.6%
	Diffuse reflection	$\Delta Rd_{cl} = 2.88.tr^{0.5}$	$R^2 = 0.786$ $MAE = 0.91$	ER = 12.9%
	Visual classification	$\Delta vis_{cl} = 0.218.tr^{0.5}$	$R^2 = 0.750$ $MAE = 0,08$	ER = 14.5%

Table 10. Models and statistical parameters that describe the behaviour of the variables: delta E, diffuse reflection and visual classification, in the laboratory and in free movement

As table 10 shows, the statistical parameters related to the process developed in the laboratory, for both delta E and for the diffuse reflection lie around the determination coefficient < 0.5 and/or relative error >25%. On the other hand, the visual classification keeps the determination coefficients high and the relative errors within acceptable levels for both conditions. Thus, from a statistical point of view, the visual classification based on gloss consists of the property with the smallest margin of predicted error and therefore, must be considered the most appropriate for estimating the useful life of glazed ceramic tiles subject to abrasion. It is interesting to note that the visual classification based on gloss also showed satisfactory results in another study[1], which analysed the wear of beige and brown ceramic tiles, with and without gloss.

Thus, the variation of the appearance obtained through the abrasion test and the variation of the appearance obtained through pedestrian traffic in free movement is proportional, respectively, to the square root of time, given in minutes, and to the square root of traffic, given in million people. Figure 8 shows the graph of the evolution of the phenomenon.

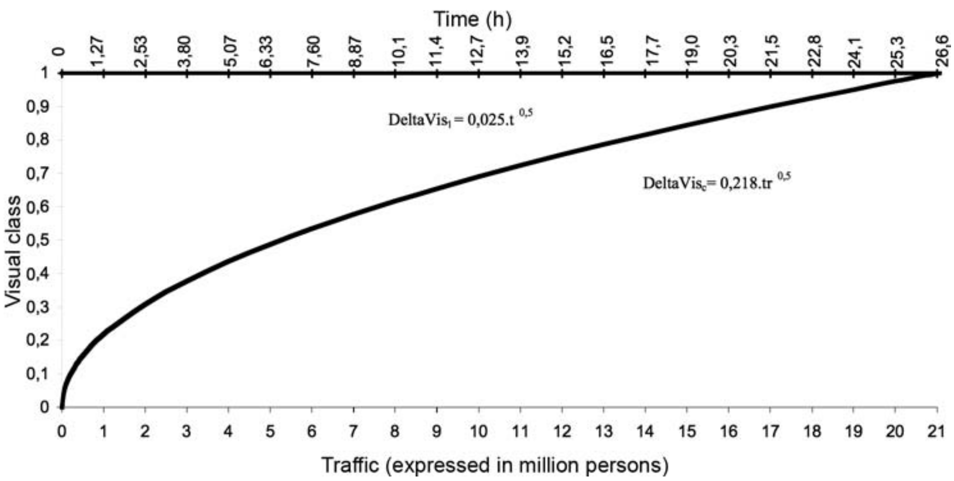

Figure 8. Graph of the models that describe the variation of appearance as a function of test time and pedestrian traffic

The acceleration factor can be estimated from the equality between the equations that describe the behaviour of the material in the field and in the laboratory, as expressed in equation 1. In this equation, one minute in the laboratory corresponds to the traffic, in free movement, of thirteen thousand two hundred people. The acceleration factor enables estimating the future performance of the ceramic material, under real conditions of use, from the test method proposed in this study.

$tr = 0.0132.t$ (equation 1) where, tr is expressed in million people and t in minutes.

The restraining movement, in turn, represented by the mean exponent 0.31, as indicated in table 9, shows that the relation between test time and pedestrian traffic is not linear; therefore, the apparatus developed in this study does not suitably reproduce the wear mechanism caused by the restrained traffic and, consequently, is not recommended for inferences on the effect of this movement.

8. FINAL CONSIDERATIONS

In this work, a model has been proposed that allows estimating in the laboratory the behaviour of glazed ceramic tiles, under real conditions of use, through an accelerated test. A field study has also been conducted, whose conditions of aggressiveness were associated with the load and abrasive concentration variables.

Of the five response variables used to evaluate wear from the point of view of appearance, the specular reflection and the mean roughness, Ra, did not show a satisfactory relation between the real phenomenon and the one simulated in the laboratory. In the first case, this behaviour is possibly associated with the difficulties of the spectrophotometer to interpret the gloss when surface variations occur. In regard to the other properties: diffuse reflection, delta E and visual classification based on gloss, it was gloss which provided the best statistical parameters.

As a result, it is proposed to adopt the visual classification to estimate the useful life of glazed ceramic tiles subject to abrasion by pedestrian traffic. The visual classification must be performed under standard observation conditions, related to the luminosity and geometry which enable gloss visualisation. The visual classification was efficient, and allowed identifying small variations between the original and abraded situations. Finally, the variation of the appearance resulting from the abrasion test and the variation of the appearance resulting from the traffic of persons, in free movement, are proportional, respectively, to the square root of time, given in minutes, and to the square root of traffic, given in million people. Therefore, it is possible to establish an acceleration factor that enables estimating the future performance of this ceramic material, under real conditions of use.

REFERENCES

[1] ABITANTE, A. L. R. **Estimativa da vida útil de placas cerâmicas esmaltadas solicitadas por abrasão através de ensaios acelerados.** 2004. 257f. Tese (Doutorado em Engenharia) – Escola de Engenharia. Departamento de Engenharia de Minas, Metalúrgica e de Materiais (PPGEM) da Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil, 2004.

[2] ABITANTE, A. L. R; BERGMANN C. P.; RIBEIRO, J. L. D., Selección de Indicadores del Comportamiento de Baldosas Cerámicas Esmaltadas Sometidas a los Efectos de Desgaste por Abrasión**.** In: WORLD CONGRESS ON CERAMIC TILE QUALITY, 2006, Castellón, **Proceedings**, Spain: Qualicer 2006, p.- (in press)

[3] AMERICAN SOCIETY FOR TESTING AND MATERIALS. In: ANNUAL BOOK OF ASTM STANDARDS. **ASTM D 523-89**: standard test method for specular gloss (Reapproved 1994). Philadelphia, 1998, p. 32-36.

[4] _______ In: ANNUAL BOOK OF ASTM STANDARDS. **ASTM E 632-82**: standard practice for developing accelerated tests to aid prediction of the service life of building components and materials (Reapproved 1996). Philadelphia, 1998, p. 298-303.

[5] ______ In: ANNUAL BOOK OF ASTM STANDARDS. **ASTM D 1729-96**: standard practice for visual appraisal of color differences of diffusely-illuminated opaque materials. Philadelphia, 1998, p. 191-193.

[6] ______ In: ANNUAL BOOK OF ASTM STANDARDS. **ASTM D 4449-90**: **s**tandard test method for visual evaluation of gloss differences between surfaces of similar appearance (Reapproved 1995). Philadelphia, 1998, p. 506-510.

[7] RIBEIRO, J. L. D.; CATEN, C. S. **Projeto de experimentos**. Porto Alegre: FEENG/UFRGS, 130p., 2001.