DURABILITY PREDICTION OF CERAMIC TILE SUBJECT TO ABRASION PROCESSES FROM PEDESTRIAN TRAFFIC

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ABSTRACT

Durability is an essential attribute, which must be taken into account as a basic criterion in selecting materials, in order to assure appropriate ceramic floor tile performance under given service conditions.

An apparatus designed to reproduce the movement of the human foot on walking, which simulates the abrasion process that arises as a result of pedestrian traffic, was used to study how different types of ceramic floor tile performed under actual conditions of use.

The change in surface quality resulting from wear by abrasion was assessed by using instrumental techniques, in order to quantify the changes in gloss, colour and texture that such material will exhibit in its useful life.

The maximum variation limits of these surface properties were determined in parallel, beyond which the user starts perceiving wear visually.

The study carried out will enable the evolution of these products under actual service conditions to be predicted, and will facilitate the classification of ceramic floor tile according to its application.

1. INTRODUCTION

1.1 DEFINITION OF DURABILITY

Among the various technical properties of ceramic floor tile, abrasion resistance stands out because of its importance in defining possible tile applications. The decision involved in selecting a given product as a floor covering in a specific building will not only mean that this tile must exhibit a set of appropriate technical characteristics with regard to foreseeable service conditions, but will also require these characteristics to remain unalterable for a set time.

The definition of durability, and that of such a related concept as suitability for a specific application, are given in the ASTM standards (ASTM Committee E-6 on Performance of Building Construction) as:

- The capability of a building product or component to perform the functions for which it is designed and constructed (from ASTM Recommended Practice E 362).

- Durability: the capability of maintaining the above quality for a specified time (from ASTM Recommended Practice E 362).

The use of this criterion for selecting ceramic floor tile raises the problem of its not being an intrinsic characteristic of this material, but rather depending directly on the conditions and wear mechanisms it is subjected to, so that ceramic flooring may keep its technical and aesthetic properties for a long period of time under some service conditions, whereas it can exhibit considerable deterioration very quickly under others.

With a view to predicting product durability, all the variables relative to actual use must be perfectly defined, such as:

- setting conditions (interior or exterior)
- volume and kind of traffic (pedestrian or vehicular)
- presence of external agents (abrasives, water, chemical products)

How accurate or reliable the durability prediction is for a specific service application will depend on the correct definition of these parameters.

The impossibility of quantifying these variables often hinders correctly assessing the minimum time that will elapse before a tiled surface starts showing signs of failure and impaired surface quality.

1.2 RESISTANCE TO SURFACE ABRASION

Many methods can be found in the literature for determining resistance to surface abrasion. However, the most widely adopted procedure is the PEI method set out in European standard EN-154 "Ceramic tiles. Determination of resistance to surface abrasion. Glazed tiles", adopted by Technical Committee CEN/ TC 67, of the European Standardization Committee (CEN).

The method involves subjecting the glazed tile surface to the effects of an abrasive load consisting of variously sized steel balls, corundum and distilled water in a standard abrasion tester, through progressive abrasion stages up to 1500 revolutions.

The test specimens are then visually inspected after cleaning and drying, under the lighting conditions and at the distance specified in the relevant standard, and the material is classified according to the lowest abrasion stage at which failure becomes visible.

The resulting wear is however not uniform within the tested surface area. There is a graduation which increases radially from the centre of the test specimen outwards, owing to the circular movement of the abrasive load across the glazed tile surface.

The lack of correlation between the results obtained with the PEI method, and the wear that arises under real service conditions, led to the design of an apparatus that would be able to simulate the abrasion mechanisms produced by pedestrian traffic.

1.3 APPARATUS FOR SIMULATING WEAR BY ABRASION CAUSED BY PEDESTRIAN TRAFFIC

The prototype, called a "TRIBOPOD", consists of an electropneumatic system, designed and built to reproduce the human gait.

The apparatus is fitted with a sole-shaped, 15 mm thick sheet of wulcollan, of Shore A 90 hardness, whose trajectory simulates how a foot treads on the floor. The sequential movement is controlled by an automatic programmer hooked up to a set of position and synchronism sensors, providing efficient control of the assembly's operations.

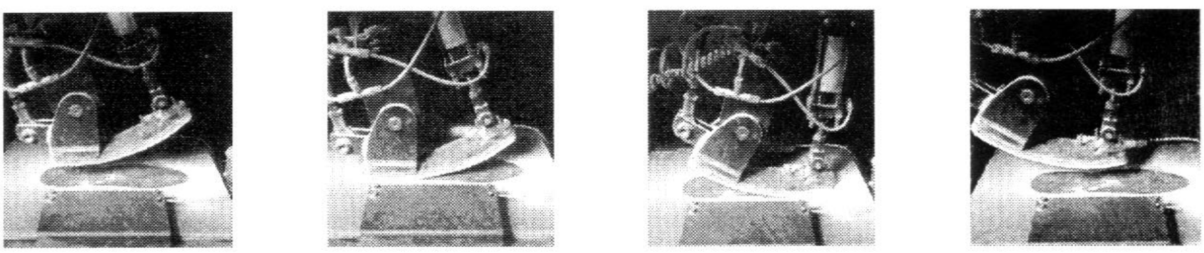
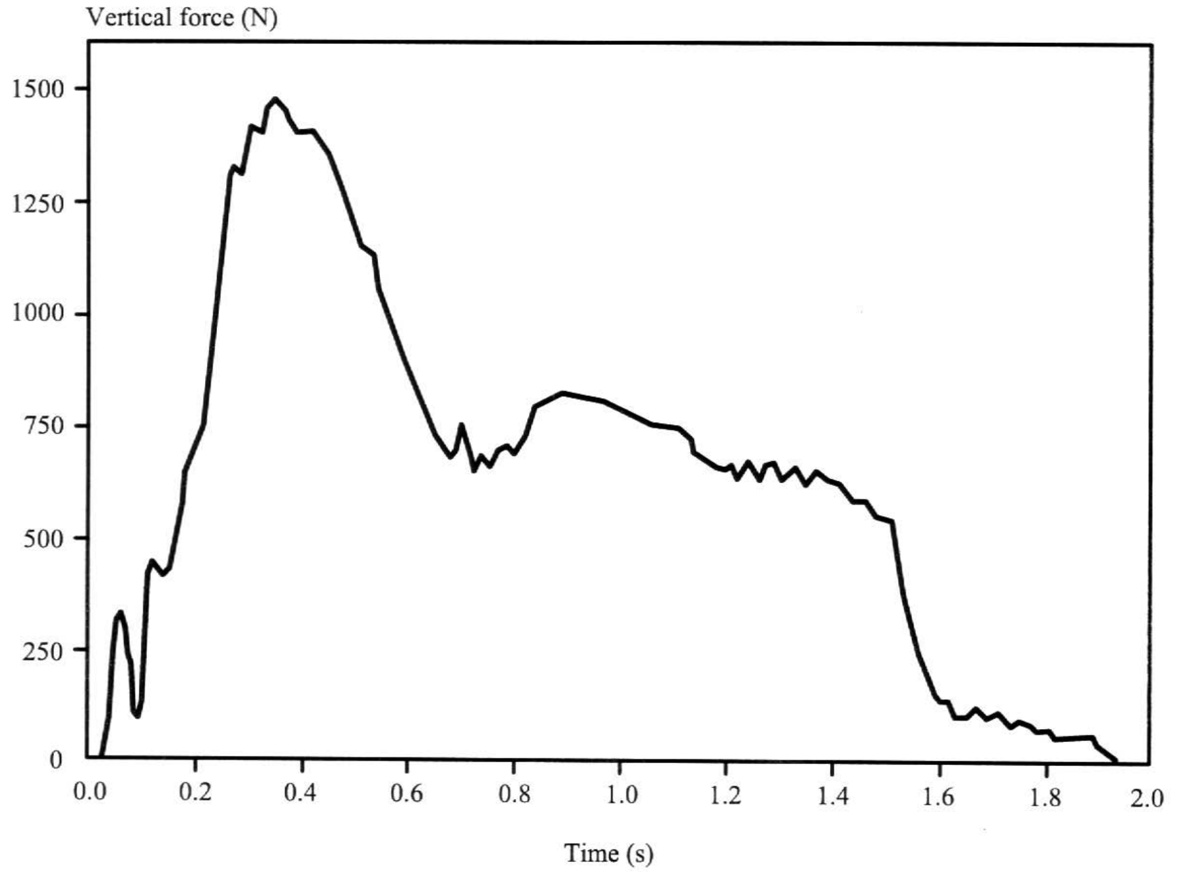


Illustration 1. *Tribopod movement sequence*

The apparatus also contains a multicomponent system of three extensometric force transducers, set at the vertices of an equilateral triangle, which supports the platform holding the ceramic tiles. This force measurement system, which is connected to a digital oscilloscope, allows recording the vertical force exerted by the sole of the foot on the tile continuously and in real time (Graph 1), thus guaranteeing test repeatability.

Although human gait may vary, depending on the person involved, it is characterized by exhibiting two vertical force peaks. One corresponds to heel impact on the floor (pronation period), and the other to the propulsion at the front of the foot (supination period). However, the presence of this second peak depends on each person's own peculiar way of walking, and hardly exists in some cases.

The apparatus was tested by skilled biomechanical engineers, using a KISTLER multidirectional force measuring plate to verify whether the medio-lateral and anterior-posterior forces exerted by the TRIBOPOD actually matched the characteristic curves of human gait. The driving unit was set at a static weight of 74 kg, so as to simulate the force exerted by a tall person. A vibratory feeder, controlled by a programmer, sprays a constant quantity of abrasive powder between the sole and the tile, at preset cyclical intervals.



Graph 1. *Vertical force curve*

2. OBJECTIVES

The present study was undertaken with a view to developing a test method that would allow:

- Reproducing actual floor tile performance under service conditions in a dwelling unit.

- Quantitatively assessing variation in surface properties (gloss and colour), and setting the maximum limits beyond which changes become visually perceivable.

- Predicting the length of the product's useful life under expected service conditions.

3. MATERIALS

Among the extensive range of products obtainable in the marketplace, a set of 18 ceramic floor tiles were selected, which combined the gloss, colour, and surface textural qualities set out in Table 1.

Table 1

Model	Gloss 60°	Colour	Texture
1	Matt	Plain light colour	rough
2	Matt	Plain intermediate colour	smooth
3	Matt	Plain intermediate colour	rough
4	Matt	Plain dark colour	smooth
5	Matt	Plain dark colour	rough
6	Matt	Light multicolored	smooth
7	Matt	Light multicolored	relieved
8	Matt	Intermediate multicolored	smooth
9	Matt	Intermediate multicolored	rough
10	Matt	Dark multicolored	smooth
11	Semigloss	Plain light colour	smooth
12	Semigloss	Light multicolored	relieved
13	Semigloss	Intermediate multicolored	smooth
14	Semigloss	Intermediate multicolored	relieved
15	Glossy	Plain light colour	smooth
16	Glossy	Plain dark colour	smooth
17	Glossy	Light multicolored	relieved
18	Glossy	Dark multicolored	relieved

4. EXPERIMENTAL PROCEDURE

4.1 TESTING CONDITIONS

As predicting a material's durability largely depends upon the actual conditions to which the material involved will be subjected, all the variables affecting a product's performance in an actual application must be defined. In practice, service conditions in a dwelling unit may vary considerably, depending upon:

a) Floor tile location: frequently transited areas like entrances and corridors will undergo more vigorous wear than bathrooms and bedrooms.

b) Position of the dwelling unit and the building: the amount and type of abrasive present will vary noticeably according to whether the dwelling directly accesses the exterior, lies in a block of flats, is close to building works, beaches, etc.

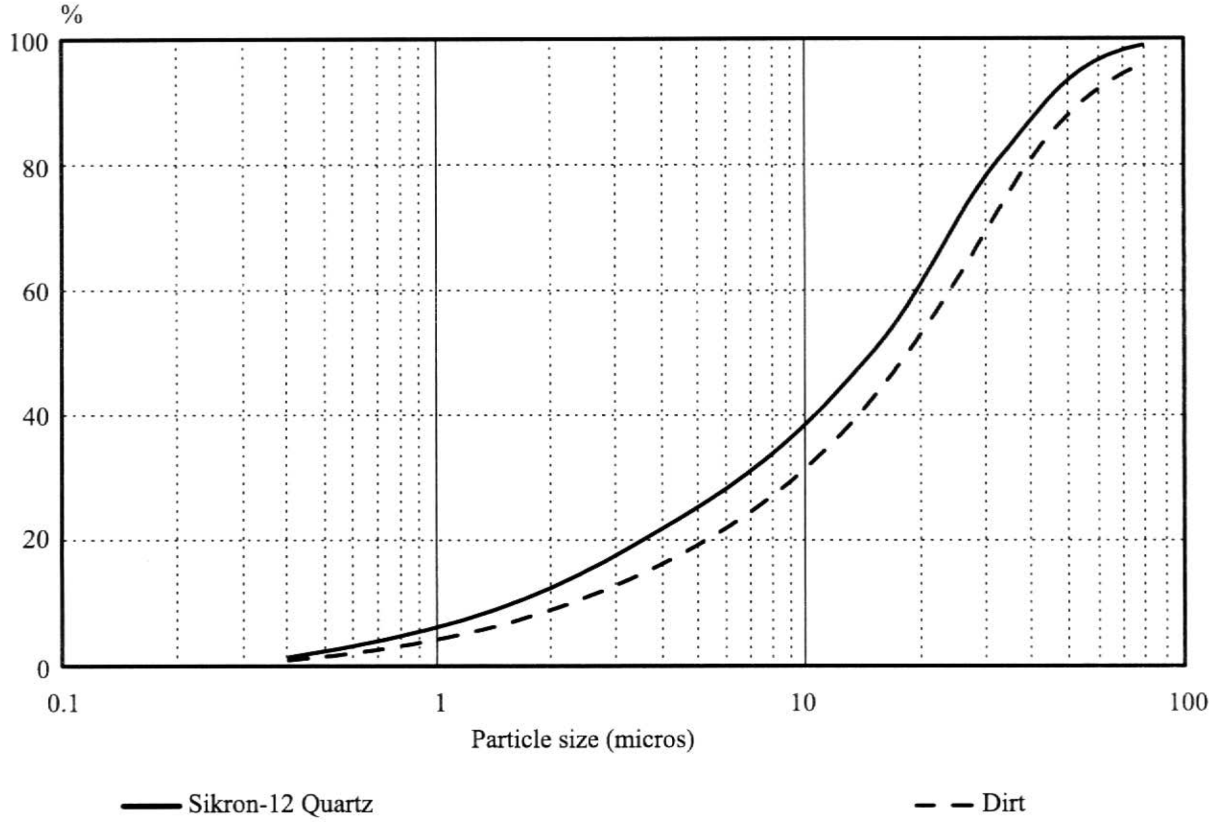
c) Cleaning frequency: abrasion will be more or less severe in terms of the amount of abrasive present, and the protective measures used to keep such abrasives from entering the dwelling (door mats etc.).

It will therefore be difficult to establish average parameters that can be applied to every kind of housing or dwelling unit, and which will assure reliable durability predictions for every situation.

In the present study, a working method has been defined, which reproduces the most unfavourable service conditions to which ceramic floor tile might be subjected.

The apparatus used exerts a repetitive, monodirectional force on the same part of the tile in order to reproduce the most demanding conditions in each case, such as for instance a building entrance.

The abrasive used to simulate wear was chosen as a result of a study of the particle-size distribution of various dirt samples taken at residential buildings; Graph 2 depicts a plot of the particle-size distribution of the quartz used and the abrasives obtained in actual conditions.



Graph 2. *Dirt and quartz particle sizes*

The continuous presence of excess quartz on the tile surface is assured through a feeding system, which is programmed to provide new abrasive after every ten tribopod steps.

Greater wear is thus produced than would be expected in any kind of private dwelling. This wear is furthermore always assessed at the most abraded part of the tested tile. The resulting durability predictions, based upon the changes that occur in tile surface properties under these conditions, will therefore always involve more demanding conditions, than the actual service conditions that this floor tile will foreseeably encounter on installation.

4.2 ABRASION ASSESSMENT METHODS

Another of the great problems involved in the methods currently being used for classifying the abrasion resistance of floor tile, lies in their dependence on qualitative assessment systems based upon the visual perception of wear, which as a result of their subjectiveness, raises serious problems for the quantification of abrasion, since such systems depend on the visual capacity of the observer and the observation conditions (lighting, distance, angle of vision).

Since in order to predict floor tile durability, it is necessary to quantify the degree of deterioration that arises as a result of a given number of steps, it was decided to employ instrumental techniques to appraise the resulting wear.

The following methods were used:

- Measurement of change in surface gloss
- Measurement of change in surface colour

4.2.1 Measurement of change in surface gloss

One of the most sensitive optical properties with regard to changes in texture produced by abrasion processes, is that of surface gloss.

The measurements were run using a standard reflectometer, at a 60° angle, adjusted using a primary reference of polished black glass, with an assigned gloss value at 60° of 93.

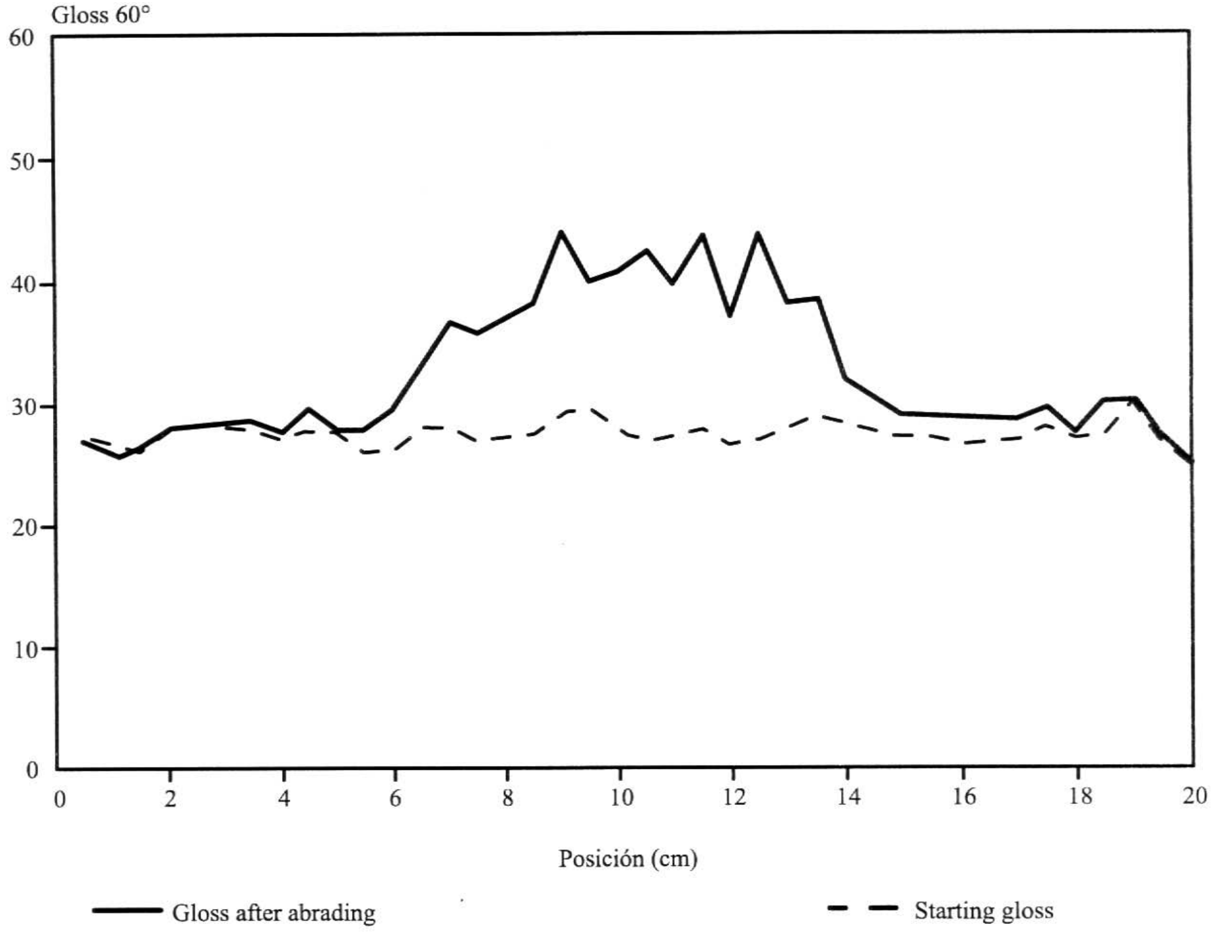
Among the three possible angles of incident light usually adopted for measuring surface gloss (20°, 60°, and 85°), each recommended for a given gloss interval, in decreasing order, the value of 60° was selected because it covers most of the range (medium gloss), since measurements performed at different angles of incidence cannot be compared.

The equipment is fitted with a powerful light source and receptor, which were set at an angle of 60° relative to the surface to be measured, as set out in standard ASTM D 523 "Test Method for Specular Gloss".

Surface gloss profiles were made in the direction of the advancing step, along the central line of the track, both before and after wear simulation, in order to analyze the variation that arose across the whole tested surface.

The difference between both profiles yielded the change in medium gloss at each abrasion stage.

In prior testing, it was shown that the area exhibiting loss of its characteristics most rapidly was the area where the front of the sole trod, whereas the remaining track showed less marked deterioration (Graph 3). With a view to appraising the most demanding service conditions, the values of the gloss variation were taken as the average difference between the gloss found before and after abrading, in the region exhibiting the greatest change.



Graph 3. Example of gloss measurement

4.2.2 Measurement of change in surface colour

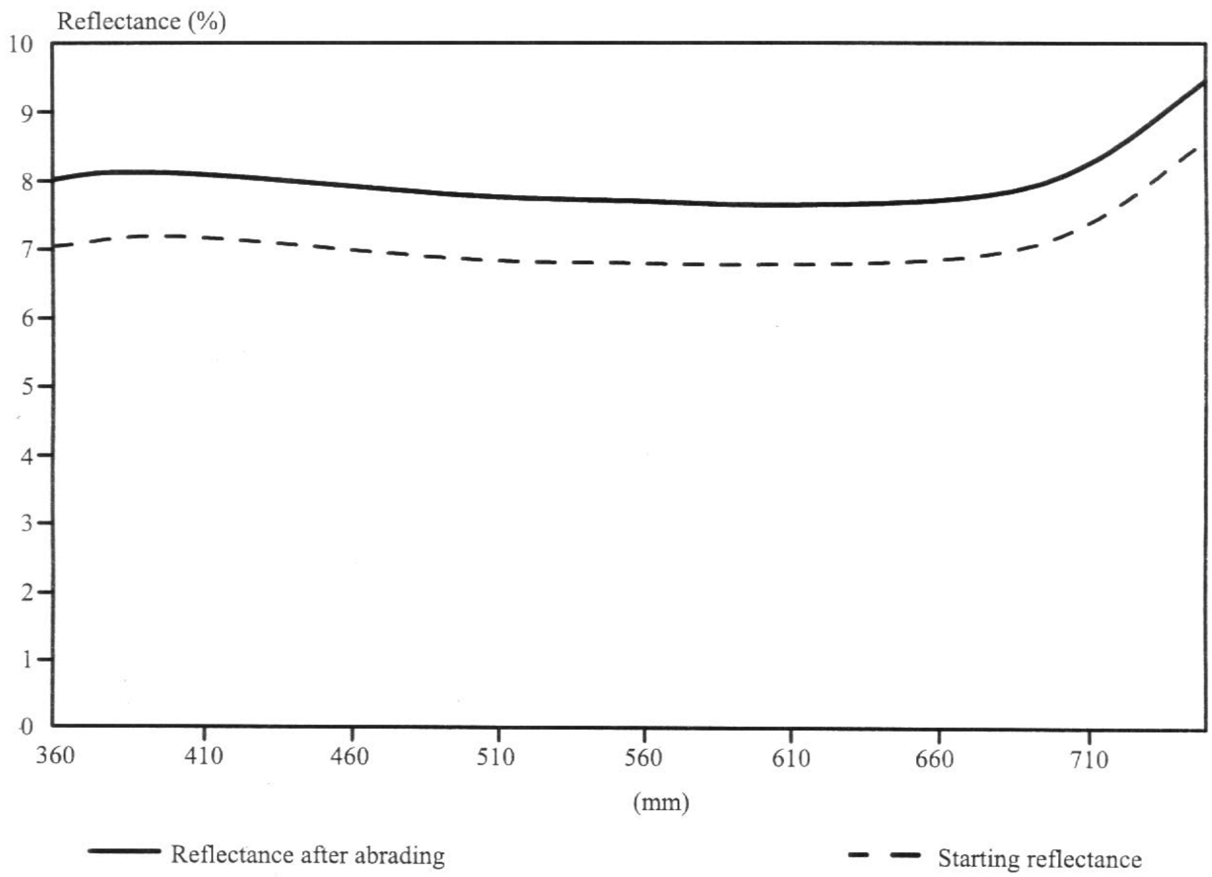
The measurements were run with a D/8° diffuse reflectance spectrophotometer. Six measurements were performed on each tile in the region where the front of the apparatus rested, to assess the variation in the area subjected to most wear. These measurements were averaged, assigning a reflectance curve to each abrasion stage.

As most of the tile models were coated with several layers of different colours, and colour changes could be heterogeneous across the spectrum, it was decided to work with the instrument's basic measurements, that is, reflectance curves in the spectrum 360-750 nm, instead of using the absolute chromatic coordinates (L*, a*, b*).

In testing, the effect caused by wear generally appeared as a loss of colour saturation, with no change in the shape of the reflectance curve. Therefore, to quantify abrasion, the difference was measured between the starting and final reflectance curves of the wear process.

It can be observed in Graph 4 that the reflectance curve corresponding to the abraded part of a dark-coloured tile shifts towards higher values (lighter shades).

To assess the change in colour, the average value was used of the differences found between both curves at each point in the spectrum.



Graph 4. *Example of colour measurement*

4.3 ADMISSIBLE VARIATION LIMITS

Durability has been defined as the capability of a material to maintain its "serviceability" over a specified period of time. If a product is considered serviceable as long as the user does not appreciate any loss of the product's functional or aesthetic characteristics, the durability prediction of floor tile subject to abrasion will require quantitatively determining what the maximum variation limits are of tile properties, within which no visually perceivable loss occurs of its original characteristics.

A correlation must therefore be established between the subjective visual perception of the users, which defines the start of impaired serviceability, and the quantitative instrumental measurements that allow determining how the material evolves under abrasion.

4.3.1 Visual classification

The resolution of any element of measurement depends on the conditions being used. Therefore, in order to quantify the human eye's visual perception capacity, the conditions involved in performing the observation must be clearly defined (intensity and type of illumination, distance and angle of observation).

As in practice, the conditions of observation in different dwelling units can vary considerably, and general values cannot be set to cover every case, it was decided to visually assess each property under a specially chosen set of conditions, in order to facilitate the perception of differences.

The admissible variation limits that were thus obtained would then represent the most demanding case of visual observation, and would therefore assure the validity of the durability prediction. To suppress the subjectivity stemming from an individual observer's assessment, each abrasion stage was appraised by ten qualified technicians, in order to establish the margins of variation that foreseeably arise when different persons perform the classification.

This is why instead of having a single limiting value for every group of materials and each characteristic, a transition band has been defined between the domain of perceivable and non-perceivable change. The band width was set to ensure 90% probability (agreement of nine technicians in the visual classification).

The visual classification methods used in each case were as follows:

a) Variation in colour:

Observation distance:	2 metres
Angle of observation:	≈ 39.5° (height of 1.65 m)
Luminous intensity:	300 lux
Lighting direction:	vertical (to suppress the perception of gloss changes as a result of specular reflection)

b) Variation in gloss:

Observation distance:	1 metre
Angle of observation:	≈ 25°
Luminous intensity:	1000 lux
Lighting direction:	≈ 25° (specular reflection in the direction of the viewer)

4.3.2 Limits of visual perception of colour change

Different, representative models were chosen from the following product groups:

1) Light colour — Average starting reflectance ($I_0 > 60$)

2) Intermediate colour — Average starting reflectance ($30 < I_0 < 60$)

3) Dark colour — Average starting reflectance (I0 < 30)

Six colour measurements were performed on the unabraded surface of each model, calculating the average values of the starting reflectance curve (I_0).

Each model was subjected to progressive abrading stages, using the pedestrian traffic abrasion simulator (TRIBOPOD). Every abrasion stage was visually classified under the above conditions, instrumentally quantifying the variation in reflectance (ΔI) produced by the abrasion process.

Using the values of ΔI corresponding to a safety margin of 90% in the visual classification, the limits of the transition band were determined for each of the tested typologies.

4.3.3 Limits of visual perception of gloss change

In order to establish a correlation between visual perception and the instrumental measurement of gloss change, tile models were chosen, belonging to the following typologies:

1)	Smooth matt surface	Starting gloss 60° $B_0 < 30$
2)	ough matt surface	Starting gloss 60° $B_0 < 30$
3)	Relieved matt surface	Starting gloss 60° $B_0 < 30$
4)	Smooth semigloss surface	Starting gloss 60° $30 < B_0 < 70$
5)	Relieved semigloss surface	Starting gloss 60° $30 < B_0 < 70$
6)	Smooth glossy surface	Starting gloss 60° $B_0 > 70$
7)	Relieved glossy surface	Starting gloss 60° $B_0 > 70$

The various models underwent progressive abrading stages. Each stage was visually classified under the conditions set out above, while instrumental measurements were carried out in parallel, using a reflectometer with a 60° angle of incidence.

Using the values of ΔB corresponding to a safety margin of 90%, the limits were set of the transition band for each of the tested typologies.

4.4 DURABILITY PREDICTION

After establishing the number of tribopod steps required to produce a perceivable variation in any of the properties involved, in order to predict product durability on aging under given service conditions, the extent to which such floor tile is used must be known, i.e. how many steps will foreseeably be taken across it over a specified time.

As the number of daily steps in a dwelling unit may vary according to the location considered in the building, it was decided to use the entrance to the dwelling as the reference area to define the degree of use, since this an area that is necessarily transited, and is the place where abrasive particles enter the dwelling.

Using this criterion, a theoretical estimate was made of the number of steps that are taken yearly across the threshold of an average dwelling inhabited by four persons, as follows:

No. of persons living in the dwelling:	4
Entrance/exit:	2
Days/year used:	330
No. of exits/day:	4
Correction for treading area	0.5

The product of these factors yields a total of 5280 steps/year, which represents an estimated 50,000 steps every 10 years across the threshold of a dwelling.

As the simulation is conducted for the area subject to the greatest wear, and the variation is assessed of the surface properties in the most abraded part of each tested tile, the resulting data refer to how the most unfavourable service conditions impact installed floor tile after ten years' use.

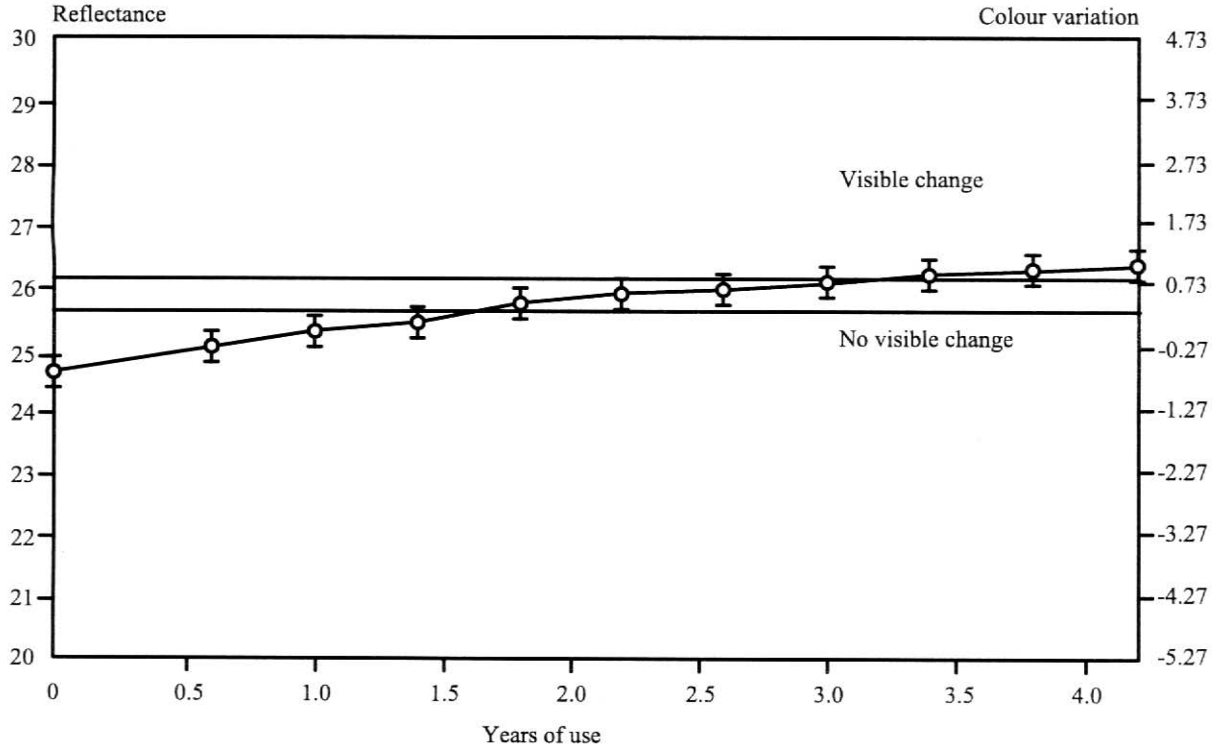
5. RESULTS AND DISCUSSION

5.1 CONFIRMATION OF THE METHOD

In order to verify whether the proposed prediction is appropriate, tests were carried out on ceramic floor tile that was manufactured in the 80s, and whose durability under actual service conditions is known, based on information stemming from consumer claims.

These models were subjected to successive abrasion stages, each involving 2000 tribopod steps, according to the procedure set out previously, until exceeding the foreseeable maximum serviceable period, while measuring instrumentally the variations in gloss and colour that arose from abrasion.

Graph 5 shows a plot of the evolution of surface colour as a function of time in one of these models, which had a plain dark brown, matt surface, corresponding to models known commercially as "leather" designs, and having an expected durability of 2-3 years in residential interior applications.



Graph 5. *Evolution of the variation in colour of a "leather" tile design*

This material exhibited a progressive increase in reflectance towards lighter colours, reaching the transition band after 1.5 years, and leaving it before 3.5 years, without showing any significant variations in gloss during the first four years.

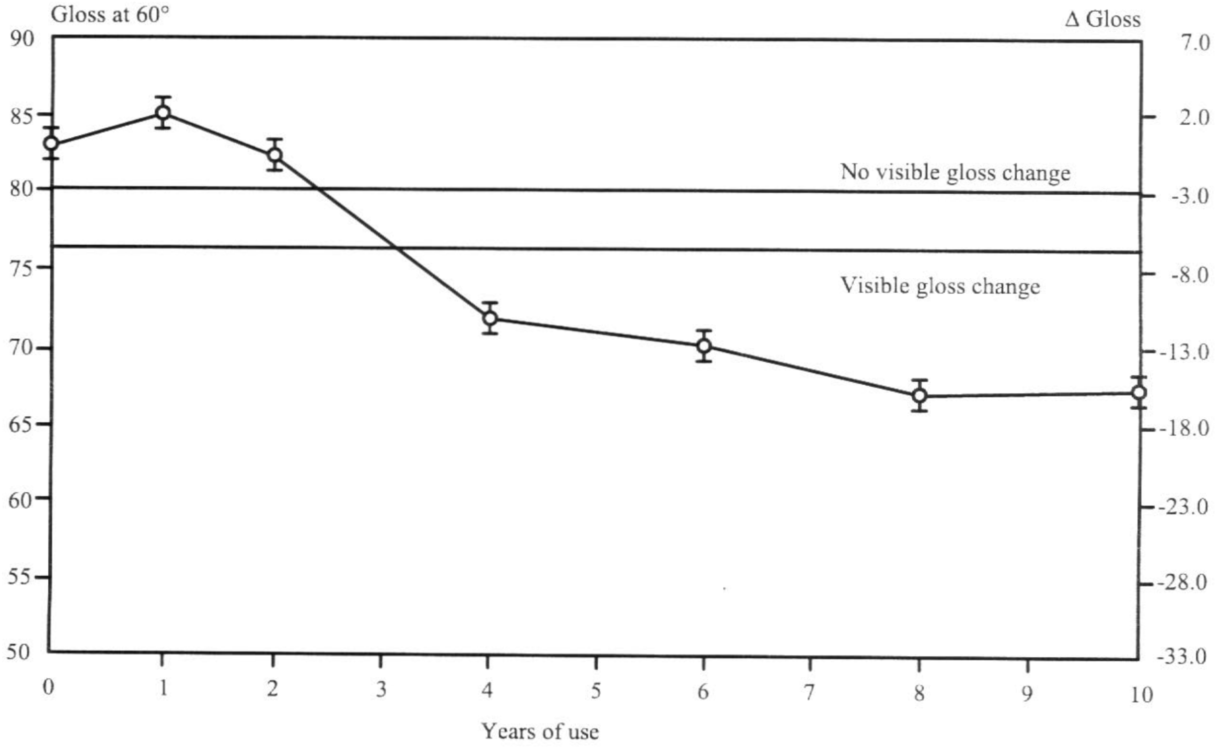
In each case, the tested models reached the admissible variation limit in slightly shorter times than those expected for actual service conditions, thus corroborating that the proposed testing system and appraisal method for predicting durability is always more demanding than the actual service conditions to which ceramic floor tile installed in a dwelling is subjected.

5.2 EVOLUTION OF DIFFERENT TYPES OF FLOOR TILE SUBJECT TO ABRASION

Tests were carried out on models corresponding to each of the studied typologies, to reproduce their performance in residential service conditions over a 10-year period.

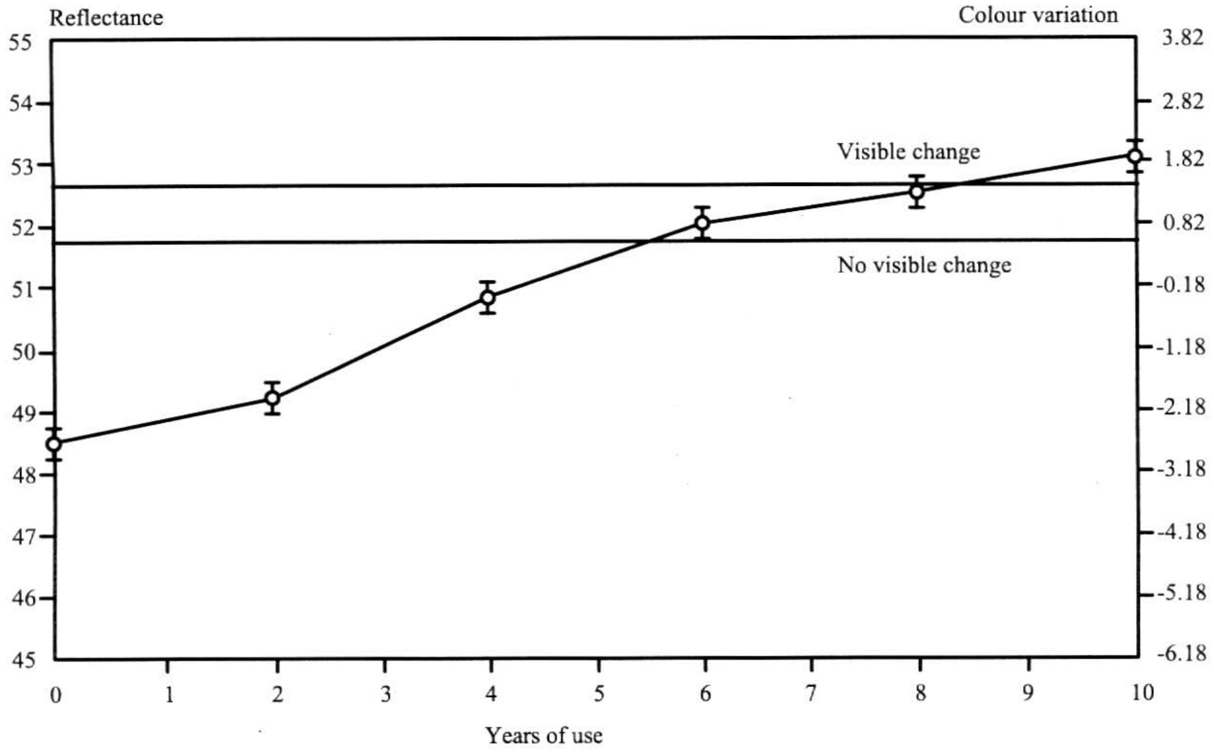
On analysing the outcomes, no general trends were found for the evolution of each kind of studied tile, since tile performance did not only depend on starting surface properties (gloss, colour and texture), but rather depended basically on surface design and the characteristics of the glaze used.

The following graphs detail the variations in colour and gloss of some models, and indicate the maximum gloss and colour variation limits of each typology. The minimum time required to reach the central part of the transition band in some surface properties has been assigned to each model as its durability parameter.



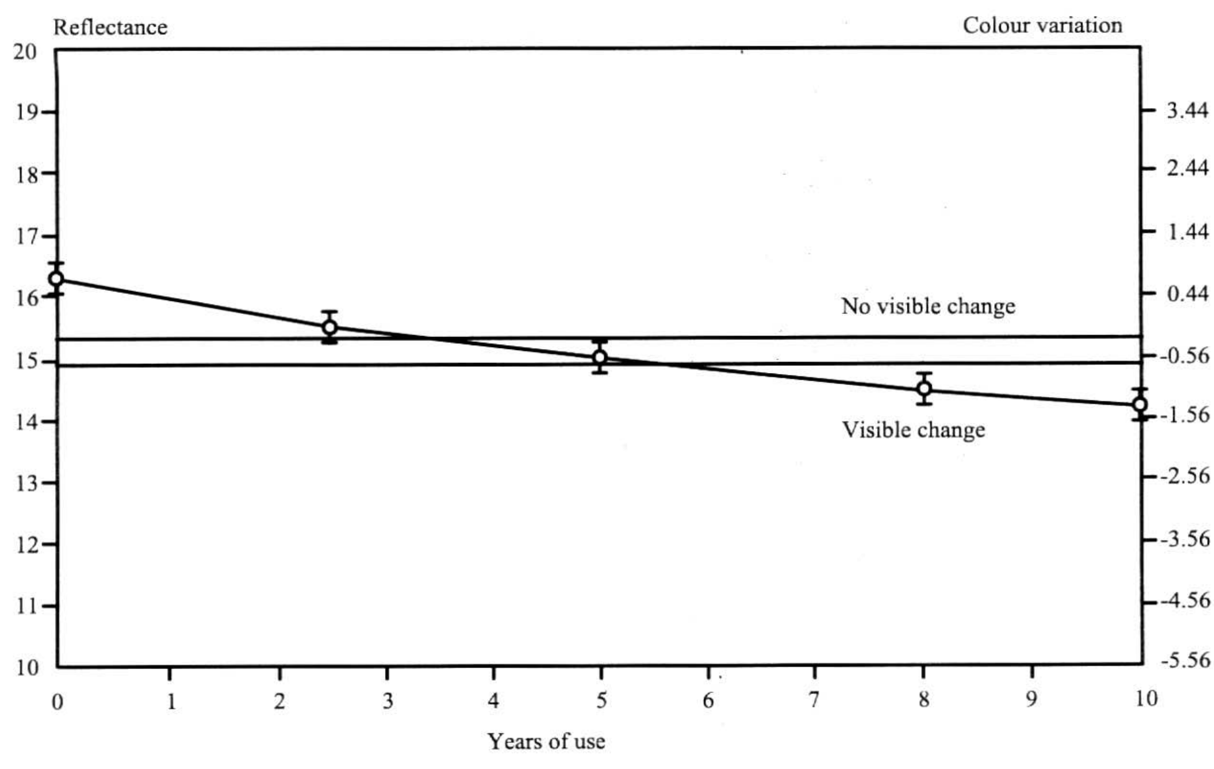
Graph 6. *Evolution of gloss in a smooth glossy model*

Graph 6 depicts how gloss evolves in a light-coloured model, with a smooth, glossy surface. After a slight initial increase, gloss decreases noticeably after 2 years' service. The model exhibits no significant variation in colour over this period.



Graph 7. *Evolution of colour in a screen-printed, multicolored, matt model.*

Graph 7 reports the evolution towards lighter-coloured shades (increased reflectance) of a model with various, differently coloured screen prints, which starts to exhibit abrasion after six years' service.



Graph 8. *Evolution of colour in a model with a dark base colour and a white granular overglaze*

Contrary to the previous model, this tile surface darkens as a result of the progressive loss of the white granular overglaze, which starts becoming noticeable after the fourth year.

6. CONCLUSIONS

The study allows drawing the following conclusions:

- An apparatus has been designed, which is capable of reproducing the abrasion phenomena caused by pedestrian traffic, thus allowing how ceramic floor tile will perform in actual service conditions to be determined beforehand.

- On using instrumental techniques to measure floor tile surface properties, a methodology was developed to replace subjective visual classification systems, and quantify the admissible variation limits of these properties, beyond which the material starts showing signs of failure and impaired surface quality as a result of abrasion.

- The proposed method allows classifying floor tile in a reliable manner, in terms of its durability in the face of abrasion in actual service conditions, thus eliminating the risk of subsequent claims as a result of an inappropriate choice of tile for applications under specific expected service conditions.

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