

NEW METHOD FOR ACCELERATED EVALUATION OF CERAMIC FLOOR TILE DURABILITY ON EXPOSURE TO ABRASION

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ABSTRACT

The increasing diversification in the use of ceramic floor tiles, which currently encompasses all types of housing and public domains, including external applications, urban furnishing and hypermarkets, requires having product selection criteria that assure economically reasonable durability in any possible service conditions. Unfortunately, despite recent revision, neither of the two respective standard test methods for glazed and unglazed tiles enables evaluating floor tile durability, because they do not reproduce actual service conditions, while also generating deceptive results, which penalise dark-coloured models compared with light-coloured ones and assign high wear resistance values to glossy surfaces that perform poorly on exposure to abrasion.

In view of the above, a new test method has been developed that reproduces the changes in surface appearance generated in actual service conditions, and is applicable to all types of glazed and unglazed surfaces. In order to have reference values to validate the new test method, a study has been conducted during the last two years of the evolution of different types of ceramic tile surfaces in two building domains subject to heavy pedestrian traffic. Based on the measurement of the changes in gloss and colour in actual service conditions, this method is shown to enable evaluating the durability of these materials in different service conditions in an accelerated way.

When the study has been completed and the most appropriate testing conditions defined in order to verify ceramic floor tile performance, the method will be submitted to Standardization Committee AEN CTN 138 Ceramic Tiles as a proposed standard test for evaluating floor tile durability.

1. INTRODUCTION

Of the different technical properties to be taken into account in designing and developing floor coverings, abrasion resistance stands out for its importance in defining the possible applications for which a material can be used. The decision to choose a given floor covering for a specific building domain, not only requires the flooring to possess a set of appropriate characteristics for intended service conditions, but also to assure that these characteristics will remain unalterable for an economically reasonable period of time.

Construction products standardisation activities have traditionally been undertaken in a parallel and individualised form by different specialised technical committees in each type of material, which has led to the development of specific test methods for the evaluation of product properties, directed in most cases towards facilitating the appreciation of differences originated by alterations in the production process, rather than estimating product behaviour in actual service conditions. In addition, until the incorporation into the European Directive for Construction Products of the concept of durability as an essential requirement of materials evaluation, the standard methods developed previously have focused mainly on the characterisation of initial product properties, determined in the laboratory prior to use, without taking into account any estimation of the capacity of the product to perform the functions for which it was designed and made.

The recent revision of the international standards for ceramic tiles has led to the harmonisation of test methods for evaluating certain properties (chemical resistance, stain resistance, etc.), which are at present equally applied to glazed and unglazed tiles. However, this is not the case in the methodology for determining floor tile wear resistance, in which deficiencies continue to persist, where two standard tests^{[1],[2]} are used that differ appreciably both in their abrasion mechanisms and the criteria used for evaluating the results. This prevents performance of unglazed and glazed products from being compared, even though both materials may be intended for the same use.

Furthermore, the test methods currently used to evaluate abrasion resistance do not allow evaluating product durability^[3] for the following reasons:

- The mechanism and elements that produce abrasion (metal balls of various sizes in the case of glazed tiles and a steel disk in unglazed tiles) are unrelated to actual service conditions, and therefore generate surface changes in the material of notably greater intensity than pedestrian traffic would cause on the flooring.
- The abrasive used, corundum in both methods, is much harder than the abrasive particles that could enter into contact with the flooring in service.
- The evaluation criteria of the results (change of colour in glazed tile and volume loss in unglazed tile) are unrelated to the surface changes produced by wear, which in most cases appear as an alteration of surface roughness and gloss^{[4],[5]}.

Consequently, not only is an objective criterion lacking to enable selecting materials with any assurance of conformance to required levels of performance, but the results obtained with the present methods can also be deceptive, since certain products with a glossy surface achieve the maximum level of abrasion resistance

(class 5) according to the classification set out in standard UNE-EN ISO 10545-7, which however turns out to be inadequate in building domains with heavy pedestrian traffic, because of the changes in gloss caused by abrasion.

The present study has therefore been undertaken with a view to defining a methodology and criteria for classifying materials intended for use as floor coverings, which by reproducing actual wear mechanisms enable evaluating these materials based on their performance, thus assuring product compatibility with service requirements, while suppressing pathologies and claims motivated by inappropriate product selection.

2. ABRASIVE WEAR MECHANISMS

Behaviour on exposure to abrasive wear, associated with the mechanical interaction between two or more materials, depends on multiple factors relating to both the mechanical characteristics of the materials and geometric aspects defining inter-material contact. Abrasion mechanisms vary appreciably depending on these variables, and brittle fracture phenomena can coexist with plastic surface deformations^[6], or some may predominate depending on the nature of the interacting elements.

In the case at hand, involving abrasion processes associated with pedestrian traffic, the tribosystem will basically consist of (Figure 1):

- a rigid body: the ceramic tile surface
- a deformable counterbody: the surface of the shoe sole
- an interface element: free moving dirt or abrasive particles
- the interface medium: air or water
- interaction between the elements: geometry and contact pressure, direction and travelling speed

In the literature surveyed, different theoretical models are proposed for analysing the abrasion process in a three-body tribosystem. Owing to the great complexity involved in fully processing all the significant variables, most of the proposals consist of simplified models that seek to relate behaviour on exposure to abrasion to certain variables, selected amongst the following:

- Relating to the rigid body: hardness, toughness, texture, roughness, porosity, impurities
- Relating to the counterbody: elasticity, relief, shape
- Relating to the interface element: hardness, toughness, particle size, particle shape
- Relating to the interaction: contact geometry, pressure, speed of movement

In most cases, the proposed models only allow assessing the influence of some of the variables, with partially satisfactory results, confirming the great variety of different tribosystems that can coexist in actual abrasion processes. Therefore, to determine the evolution of the surface of a ceramic material, it is necessary to

establish the conditions in which the mechanical actions of the abrasive elements will take place in a sufficiently defined form. As indicated previously, the available test methods are unsuitable for reproducing the wear associated with pedestrian traffic, mainly due to the mismatch between the definition of their tribological parameters and the mechanisms occurring in actual service conditions. Table 1 compares the parameters used by the different methods.

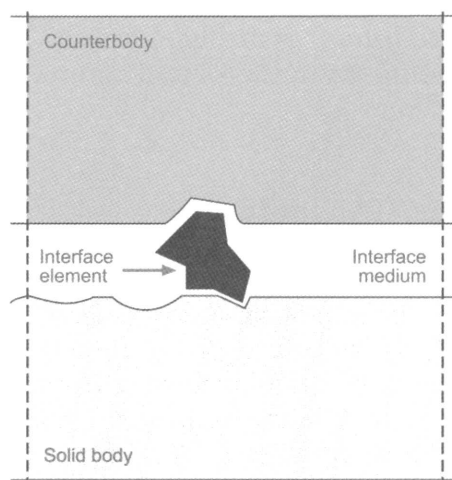


Figure 1. Three-body tribosystem

Parameter	Actual use	CAP method	PEI method	ITC method
Counterbody	Shoe sole	Steel disk	Metal balls	4S rubber
Interface element	Dirt, abrasive particles	Corundum (hardness 9) 100-300μ	Corundum (hardness 9) 100-300μ	Variable (hardness 3-7) <100μ
Medium	Air/water	Air	Water	Air
Rigid body	Ceramic tile			
Movement	Variable	Linear	Circular	Variable

Table 1. Comparison between tribosystems

3. DEFINITION OF THE NEW TEST METHOD

In designing a new test method that is able to reproduce abrasive wear in actual service conditions, the first issue to be addressed is assuring the match between the tribological parameters of the actual process and the parameters established to define the test method. As set out in Table I, the main changes required with regard to currently available methods focus on using a counterbody with deformability characteristics similar to those of commercial footwear, and adaptation of the type of abrasive used to simulate the dirt present in real situations.

Sheets of a standard rubber have been used as a counterbody, designed to simulate the characteristics of a shoe sole, as its commercial name (4S = Standard Shoe Simulation Sole) indicates, which is already being used for this purpose in some slip resistance evaluation methods.

The selection of abrasive characteristics is the critical factor in the definition of the test, since this is one of the parameters that most modifies the abrasive wear mechanism.

Since both the nature of the abrasive and its characteristics (particle size, shape, quantity present) can vary highly depending on the location of the flooring (geographic region, type of building, direct outside access, etc.), it was decided to analyse its influence on the wear process using different types of abrasive materials found in actual conditions, and to delimit their characteristics on the basis of studies conducted to validate the method in situ on floor tiles installed in building domains with heavy pedestrian traffic.

With regard to the interface medium, it was decided to carry out the tests in dry conditions in order not to limit the application of the method to glazed or low porosity surfaces, as the use of an intermediate fluid would generate significant differences in the abrasion mechanism in porous floor tiles with suction capacity. With this criterion, the method defined will be applicable not only to ceramic tiles, but to any type of flooring, regardless of the material of which it is made, enabling performance to be comparatively evaluated against other types of products.

As regards the interelement interaction, the need was considered of using a mechanism capable of acting in every direction, because in the abrasion process in real conditions there is no preferential direction of abrasive particle movement, unlike surface scratching processes.

In addition to these initial design criteria, an associated additional limitation was considered with a view to defining a test method that could be adopted as a national and/or international standard applicable to ceramic tiles. Although preliminary studies^[3] had confirmed the possibility of reproducing the abrasion mechanism in actual service conditions by means of an assembly used to simulate human foot movement when walking (Tribopod), its high complexity impedes assuring reproducibility of the results obtained in different laboratories. For this reason and despite its greater difficulty, instead of designing a wholly new method, it was decided to assess the possibility of adapting currently available methods for evaluating abrasion resistance, in order to facilitate the method's implementation in the sector at the lowest possible cost and assure the method's match with its application.

After analysing different test methods and configurations, it was decided to modify the method described in standard ISO 10545-7, keeping the abrasion apparatus used to generate the circular movement of each test specimen, however changing the elements that define the three-body tribosystem in order to adapt it to actual abrasion mechanisms. For this, the abrasive charge of steel balls has been replaced by a cylindrical bowl with three rubber studs, symmetrically distributed at 120° angles. The inside of the metal holder has also been modified by incorporating a rigid cylinder of PVC, eliminating the deformable rubber gasket to assure constant pressure by the rubber studs on the tile surface (Figure 2).

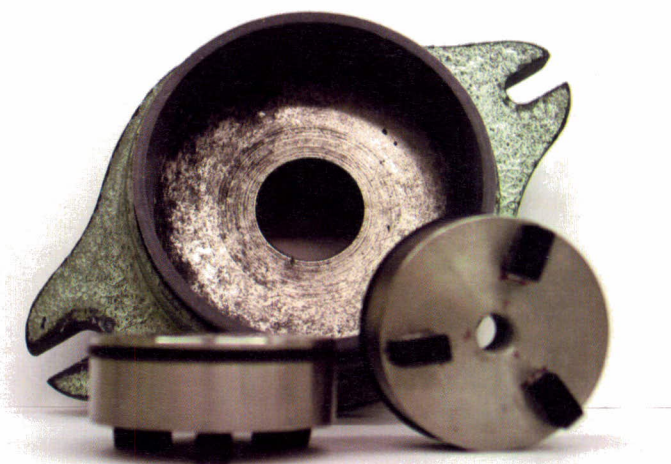


Figure 2. Modified holder and cylindrical bowl

The cylindrical bowl has a hole in the middle for introducing the set quantity of abrasive material, which spreads across the surface of the test specimen as it moves. The circular movement of the base plate of the abrasion apparatus makes the bowl rotate, which maintains contact with the inner wall of the holder (Figure 3), while the rubber studs describe a helicoid path across the centre of the test specimen in every direction, simulating the effect of sole profiles on the floor surface.

At each complete revolution of the base plate of the abrasion apparatus, the rubber studs of the bowl rub across the centre of the test specimen on six occasions, establishing a relation between the outer diameter of the bowl and the inner diameter of the holder, such that a slight advance occurs in the rotation position with each revolution, so that a full sweep of the test specimen surface delimited by the holder occurs every 10 revolutions.

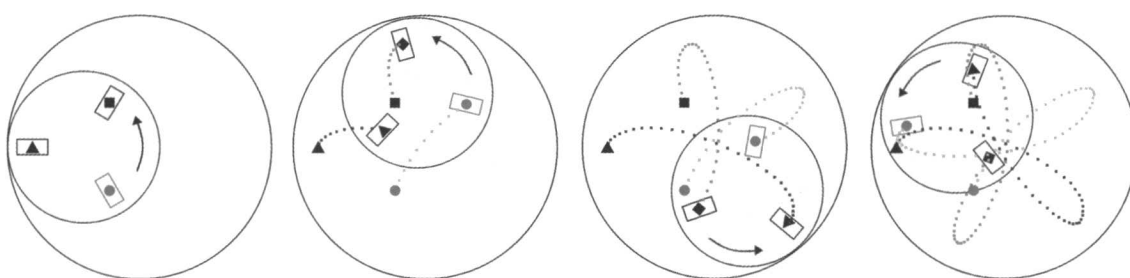


Figure 3. Movement of the bowl inside the holder

This system generates a mechanism of non-directional abrasion resembling that which takes place in actual service conditions, yielding an abrasion profile that increases from the outside until peaking at the centre of the test specimen. After performing the pre-set number of revolutions, the result of the test can be quantified by measuring the change in gloss or colour produced in the centre area of the test specimen (Figure 4).

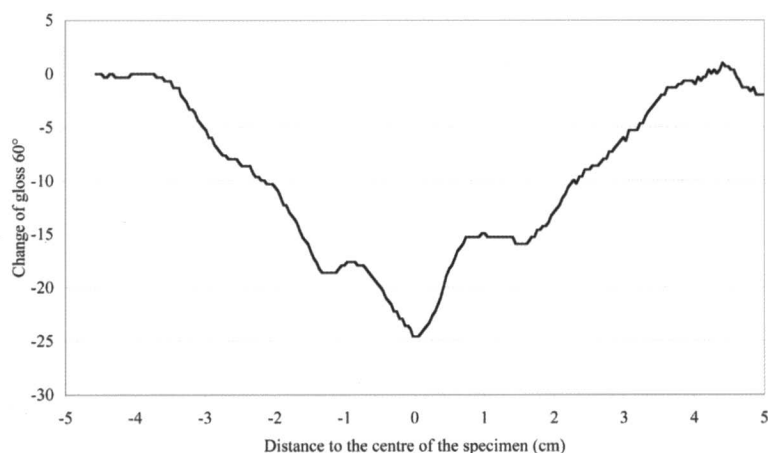


Figure 4. Gloss change at 60° in the abraded test specimen

4. INFLUENCE OF TEST VARIABLES

After defining the characteristics of the assembly for simulating the abrasion mechanisms in actual service conditions, we conducted a study of the influence of the

variables relating to the abrasive interface element (composition, particle size and quantity), which as indicated previously is the factor that most affects the development of the abrasion process.

4.1 ABRASIVE PARTICLE SIZE

In order to evaluate the influence of particle size on the wear mechanism, tests were performed using different particle size fractions of quartz with a maximum size of 100 microns, which according to preliminary studies^[3] corresponded to the typology of abrasive particles found in actual conditions. As the wear mechanism in turn depends on the relation between abrasive particle size and surface texture, the tests were conducted on two types of finishes (smooth and rough). Figures 5 and 6 plot the evolution of surface gloss in the centre of the test specimen with the different particle size fractions for the smooth and rough surfaces, with a respectively glossy and matt appearance.

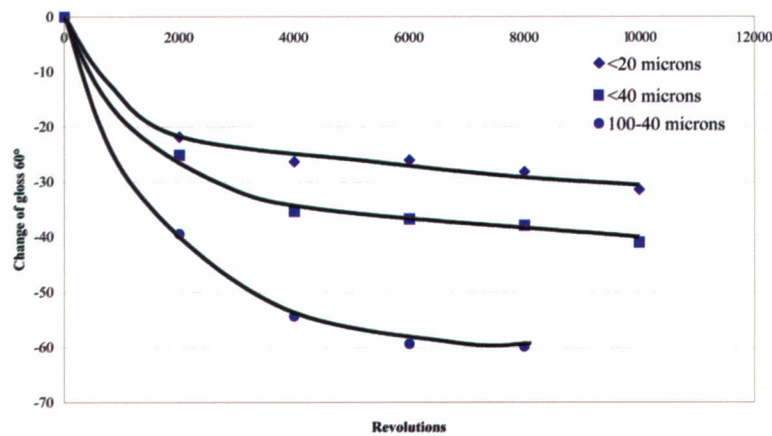


Figure 5. Tests on glossy surface

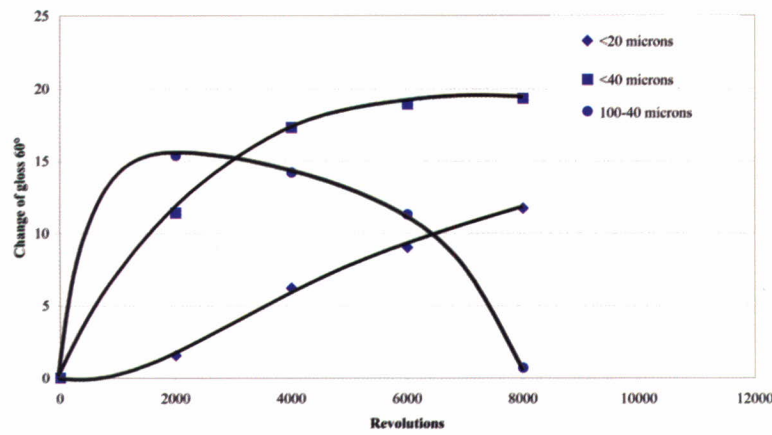


Figure 6. Tests on matt surface

It can be observed that the evolution of surface gloss in both types of materials is quite different, decreasing in the case of the glossy surface and increasing in the rough surface. Both materials confirm that raising abrasive particle size rapidly increases the intensity of the change generated in the surface. In the case of the glossy surface, this increase produces faster gloss losses, probably associated with a greater rise in surface texture. In contrast, in the matt surface there is an initial reduction of surface texture, which causes a progressive increase of gloss, although this effect

reverses after a maximum gloss level is reached, as shown in the test conducted with quartz particles measuring between 100 and 40 microns.

These findings in turn explain the differences observed in floor tiles installed in actual conditions, in which greater deterioration can be appreciated in areas close to outside accesses, whose intensity decreases with progressive advance inwards into the building area. It seems likely that the largest size particles that are carried inside on footwear from outdoors are released or retained in building entrances, causing the greatest wear in these areas. In this respect the importance should be noted of having abrasives retaining systems in the outside accesses of building premises, because these will largely limit the arising deterioration and prolong the useful life of the flooring.

4.2. NATURE OF THE ABRASIVE

In order to verify the influence of the mechanical characteristics of the abrasive, tests have been conducted on both types of surfaces, using two abrasives of similar particle size and different chemical composition. The abrasives used, quartz and dolomite, were selected in order to analyse surface behaviour on exposure to particles of greater hardness (quartz $\approx$ scratch hardness 7) and lower hardness (dolomite $\approx$ scratch hardness 3) than that of the test surface. Figures 7 and 8 plot the evolution of resulting surface gloss with both types of abrasives.

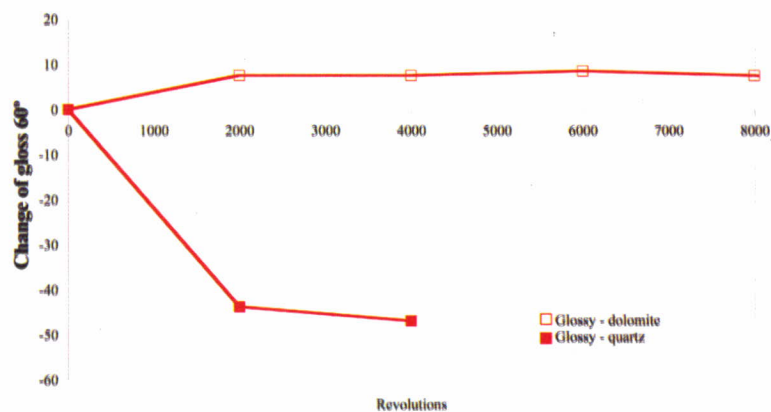


Figure 7. Tests on glossy surface

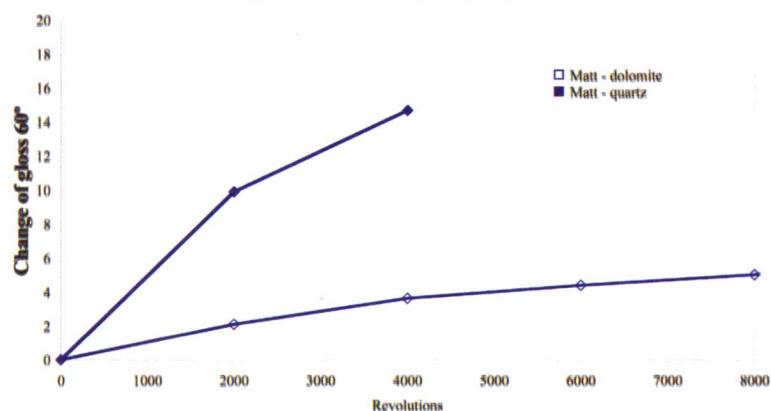


Figure 8. Tests on matt surface

The results show that the abrasive of greater hardness generates more intense changes in the surface, with gloss increasing or decreasing depending on the relation between particle size and initial tile texture.

In the case of the glossy surface, it can furthermore be observed that the abrasive of lower hardness produces a slight increase in surface gloss, although abrasive particle size exceeds the depth of the texture. This apparent discrepancy needs to be analysed, taking into account that since dolomite hardness is lower than that of the material, particle penetration will be scarce, while in addition the abrasive particles will become rounded more quickly, so that deterioration will only occur on the scale of surface roughness without modifying overall surface texture. This effect is confirmed in the tile with a rough surface, which displays a lower reduction of texture, and hence a smaller increase in gloss.

Particularly noteworthy is the enormous influence of the nature of the abrasive on the abrasion mechanism, which therefore, for a given material, can be quite different depending on the geographic area (granitic or calcareous) and location of the building (coast, inland, etc).

4.3 QUANTITY OF ABRASIVE PRESENT

Another of the variables that can modify the abrasion mechanism, and therefore the results obtained in the laboratory simulation tests, is the proportioning of the abrasive on the floor surface. In order to verify the influence of this variable on the abrasion process, comparative tests were performed on a polished floor tile surface using quartz and dolomite as abrasives. Figures 9 and 10 depict the evolution of surface gloss in the centre of the test specimens, modifying abrasive renewal times.

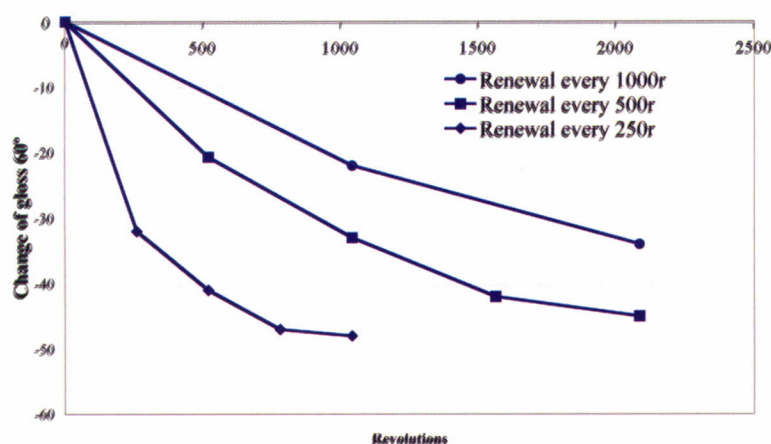


Figure 9. Tests with quartz

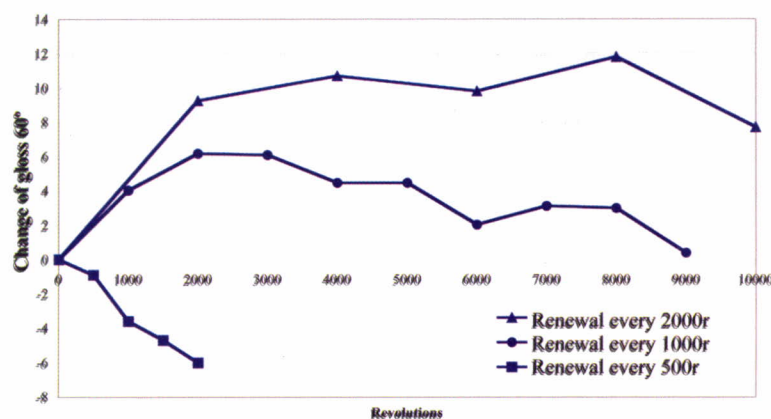


Figure 10. Tests with dolomite

In the tests conducted with quartz it can be observed how increasing the quantity of abrasive present produces a much faster deterioration of surface gloss, when the abrasive renewal period is reduced from every 1000 to every 250 revolutions. Moreover, in the tests performed with dolomite, the increase in abrasive content reduces the initially rising tendency of surface gloss, which can even reverse and generate gloss losses at renewal periods of 500 or fewer revolutions.

As was the case for the variables analysed previously, the presence of a high quantity of abrasive can appreciably accelerate surface deterioration, and will therefore limit the possible use of certain types of ceramic floor tiles in outdoor locations in which the presence of abrasive can not be limited.

5. VALIDATION OF THE NEW TEST METHOD

Data from previous studies and tests with the Tribopod had confirmed that the evolution of a material could vary quite strikingly, depending on the location of the flooring. In order to verify the suitability of the new test method for reproducing actual wear mechanisms, a study was therefore undertaken in situ in defined real service conditions^[4].

For this purpose, in the year 2001, panels of ceramic tiles were installed on the floor of the self-service passage of the two restaurants at Universitat Jaume I. As this is a one-way path, set off by a rail, optical counters were positioned at the exit next to the cash registers to quantify the number of persons that walked across the pieces being studied, which were installed in the centre zone of the panel (Figure 11). The materials used, which were specifically designed to display low wear resistance, encompassed the entire range of ceramic products, including materials with different surface textures (glossy, matt, polished, relief) and chromatic finish (plain, fumé, screen printed, etc.).



Figure 11. In situ test panel in the University self-service restaurant

A non-adhesive installation system was used to enable withdrawing and replacing the tiles, with a view to evaluating the changes generated in the surface (colour, gloss, texture) by means of instrumental measurements in the laboratory. During the last three years, each installed sample has been periodically monitored,

recording the number of persons that have walked across the panel and measuring the evolution of each tile's surface characteristics.

The results obtained provide a reference concerning the evolution of different types of ceramic materials in certain real public conditions of use. The results indicate that most of the materials display no significant alterations of colour, whereas the surface gloss is the characteristic that varies most markedly due to abrasion. Figure 12 shows that most of the materials exhibit an initial increase in surface gloss, independently of their surface finish, even in the case of the glossy polished surface that subsequently reverses its rising tendency to display a progressive loss of gloss.

This tendency towards increasing gloss had already been observed in certain materials installed in actual service conditions and was confirmed by results obtained with the Tribopod on rough surfaces. However, it was surprising that tile models with a glossy, and even a polished surface, should exhibit this rise in gloss, as well as the low level of deterioration generated in most of the ceramic tiles after the prolonged period of exposure to heavy traffic conditions. In order to appraise the actual service conditions used in the study, it should be taken into account that:

- the panels were located inside the premises, at a distance of at least 15 meters from outside accesses;
- the surfaces were cleaned at the end of each day;
- as a result of the installation system, the panels lay slightly higher than the surrounding floor plane.

The foregoing all suggests that only a scarce quantity of abrasive with a small particle size has been present on the test panels, which explains the smooth evolution of some materials that had initially been designed to provide little abrasion resistance.

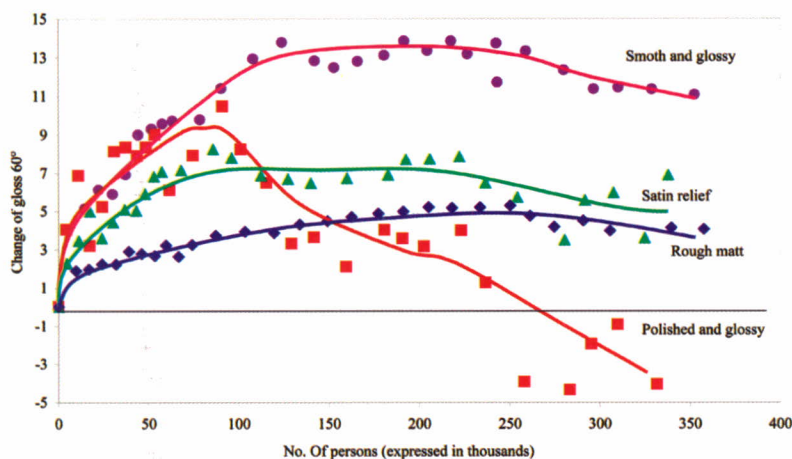


Figure 12. Initial rising evolution of gloss in the different types of surfaces in actual service conditions

After various attempts to simulate this evolution using quartz of different particle sizes as an abrasive, it was verified that the increase in gloss of the initially glossy surfaces could not be reproduced, so that it was decided to use abrasives of lower hardness to simulate these service conditions. Figure 13 plots the values obtained in the laboratory tests conducted with dolomite of particle size below 100 microns and an abrasive renewal period of 2000 revolutions, compared with the real tendency of the different materials. In the tests run with this abrasive, all the types of surfaces display an evolution similar to that observed in the pieces installed in real

conditions. In fact, the results obtained confirm that the particle size present in real conditions must be smaller than the one used in the test, since the glossy models display a slightly smaller increase, and the matt models a slightly higher rise than that observed in the samples installed in the panels.

Although these results allow concluding that the test method is able to reproduce the real abrasion mechanisms with these tribological parameters, it must be taken into account that when the parameters relating to the abrasive (hardness, particle size, quantity present) are slightly modified, the evolution of the material changes significantly. In other words, these same materials in other real locations could have exhibited a completely different evolution, as observed in certain studied building domains in which polished surfaces have displayed high gloss losses.

6. PROPOSED STANDARD TEST

As result of this study, it is intended to submit the new test method, which is able to reproduce actual service conditions, to the Technical Committee for Standardization AEN/CTN 138 "Ceramic tiles", for adoption as a standard test for evaluating the durability of ceramic floor tile. At present, studies of the repeatability of the method, as well as the definition of the criteria for visual and/or instrumental evaluation of the results, are being finalised, and the possibility is being evaluated of combining the method with a stain resistance test on the abraded test specimens, to also evaluate the stain retention capacity associated with the abrasion process.

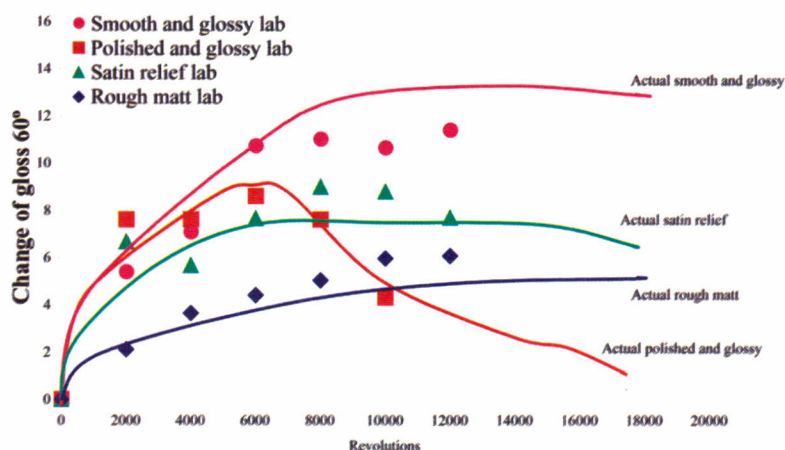


Figure 13. Reproduction of the evolution of gloss in real conditions by laboratory tests

However, definition of the conditions to be set for the standard test is still pending, as the selection of the type and characteristics of the abrasive used in the tests will be critical with regard to the final evaluation of durability, and as the method allows reproducing different real service conditions, it will be necessary to choose one or more reference conditions to enable comparing the performance of different materials. Our proposal is directed towards defining a classification of products based on a scale of different levels of use in terms of increasing aggressiveness, such that the assignment of a class assures a minimum period of useful life of the material in the conditions corresponding to this category. The test method could therefore be used to classify a material based on the material's suitability for an intended use, in line with the present tendencies of the sector.

In order to define this classification, the following variables will need to be taken into account, in decreasing order, as a function of their influence on the abrasion process:

1. Nature of the abrasive: related to the geographic area (granitic, calcareous)
2. Particle size: associated with the location of the building (urban, rural, coastal, etc.)
3. Quantity of abrasive present: based on outside access and cleaning frequency
4. Expected volume of traffic: low level (residential use) or high level (public use)

Due to the high number of possible combinations, it will be necessary to simplify the classification criteria, pre-establishing some of the variables indicated, hereby accepting that the applicability of the method will be limited to reproducing only certain actual service conditions. Obviously, a decision in this sense can only be taken by the Standardization Committee, by consensus between the different parties represented, owing to the legal and/or contractual implications that the use of a standard method for evaluating durability could entail.

7. CONCLUSIONS

The following conclusions can be drawn from the present study:

- Abrasion mechanisms in actual service conditions should be analysed from the perspective of a three-body tribosystem, in which the characteristics of the abrasive have a notable influence.
- Present test methods are inadequate for reproducing abrasion in actual conditions, owing to the mismatch in the definition of their tribosystems and the fact that the evaluation criteria used are unrelated to the surface changes that are produced by wear, which in most cases appear as an alteration of surface roughness and gloss.
- It has been confirmed that wear mechanisms can vary appreciably depending on the interface elements present, and therefore that the evolution of the surface characteristics of installed floor coverings will depend to a greater extent on the characteristics of the building domain (geographic area, location of the building, outside access, cleaning frequency, etc.) than on the expected level of pedestrian traffic.
- A new test method, applicable to all types of glazed and unglazed surfaces, has been defined, which enables reproducing different real service conditions based on the characteristics and proportioning of the abrasive used.
- Using this test methodology will enable establishing a classification of ceramic floor tiles based on tile performance, which will allow selecting products that are assured to match the requirements of their intended use.

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