

TECHNICAL REQUIREMENTS OF CERAMIC TILES FOR SPECIFIC USES

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1. INTRODUCTION

Ceramic tile manufacture has undergone widespread, on-going change over the last few years. Current manufacturing processes for these materials are highly innovative, with fully automated manufacturing yielding high quality and productivity. In Spain, most ceramic tile manufacturers use state-of-the-art technology, with company upgrading and reconversion lying at over 98% (1).

Ceramic tiles are usually marketed according to traditional tile grades (first quality, standard, second, commercial, single quality, etc.). First quality does not correspond to the definition laid down in the European standards for ceramic tiles (EN) (2), basic standard, product standards and standards for tests, sampling and basis for acceptance, so that neither invoice specifications nor box markings are carried out according to the requirements set out in these standards. On the other hand, experience has shown that market demands as far as ceramic tile characteristics are concerned, do not coincide with EN regulations either (Figure 1).

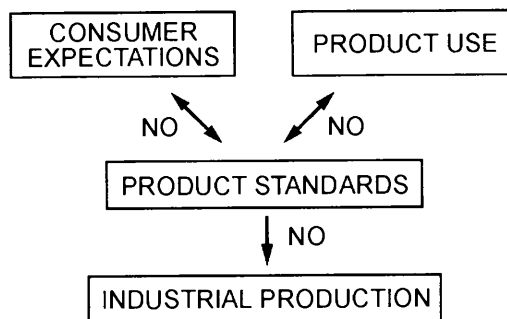


Figure 1.

Market demands are stricter than the standards, in respect of the characteristics that noticeably affect tile fixing and use, such as surface quality, dimensions and resistance to specific chemical, physical and, particularly, mechanical actions. There is furthermore a lack of definition with regard to the selection of products, in terms of the use to which they are to be put.

There is then currently a clear gap between ceramic tile use and the regulations for products and tests. This situation has led both the tile and construction industry to indicate the convenience of defining requirements of ceramic tiles for specific service applications (Figure 2).

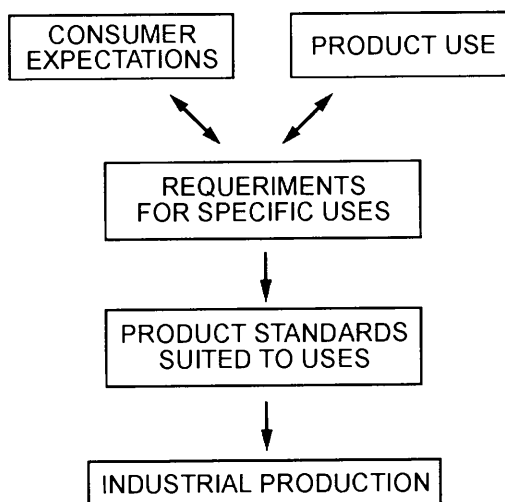


Figure 2.

These technical requirements would allow satisfying consumer expectations, marketing these ceramic products would become easier, and innumerable claims that arise as a result of unsuitable use, would be avoided.

The following will review the sections depicted in Figure 2, and an intent will be made to set out the minimum requirements of ceramic tiles for specific uses.

2. CONSUMER EXPECTATIONS

Ceramic tile quality is closely related to customer satisfaction, and the suitability for use of these materials.

Obviously, any ceramic tile will be suited to a specific use if it meets the customer's expectations.

It is therefore necessary to examine the characteristics of ceramic products, which define customer expectations (Figure 3). Three levels of ceramic tile characteristics can be observed, which define these expectations, and which will be decisive as far as marketing these ceramic products is concerned.

CERAMIC PRODUCT CHARACTERISTICS THAT DEFINE CONSUMER EXPECTATIONS	
PERCEIVABLE CHARACTERISTICS PRIOR TO USE, DECISIVE FOR THE PURCHASE	DIMENSIONS (SHAPE, SIZE), SURFACE APPEARANCE (COLOUR, GLOSS, DESIGN, ROUGHNESS, FRICTION, ETC.)
CHARACTERISTICS RELATING TO FIXING AND STORAGE (APPRECIABLE FOR THE TILE FIXER AND/OR RETAILER, BUT NOT APPRECIABLE FOR THE FINAL USER)	EASE OF HANDLING (WEIGHT, SHAPE, SIZE, THICKNESS, PACKAGING, NUMBER OF COMBINABLE PIECES, ETC.) FIXING YIELD (SHAPE, COMBINABILITY) BONDING TO BACKGROUND, STABILITY IN STORAGE (CURVATURE, CRAZING, ETC.)
SERVICE CHARACTERISTICS (PERCEIVABLE FOR THE FINAL USER, BUT UNKNOWN WHEN PURCHASED)	IMPAIRED APPEARANCE (BREAKING, FLAKING, CRAZING, INTERNAL OR EXTERNAL DIRT RETENTION, CHANGES IN COLOUR, GLOSS, OR LOSS OF SURFACE QUALITY) RELATED TO SAFETY (FRACTURES, OR INJURIES, SLIPPERY SURFACE, POSSIBLE RELEASE OF HARMFUL ELEMENTS OR COMPOUNDS) RELATED TO HYGIENE OR DISINFECTION (ADHESION, POROSITY, POSSIBLE RELEASE OF DUST)

Figure 3.

The three groups of characteristics are:

- PERCEIVABLE CHARACTERISTICS PRIOR TO USE
- CHARACTERISTICS RELATING TO FIXING AND STORAGE
- IN-SERVICE CHARACTERISTICS

a) Perceivable characteristics prior to use.

This group comprises ceramic tile dimensions (shape, size), appearance (colour, gloss, decoration, general design), and surface texture (roughness, friction, etc.).

Such are the characteristics observed by consumers on purchasing tiles. They are characteristics that subjectively and qualitatively define ceramic tile quality, so that they become determining factors when tiles are purchased.

b) Characteristics relating to fixing and storage.

This is a group of characteristics relating to the greater or lesser ease of ceramic tile installation and transport before fixing. They are decisive characteristics if the purchaser is a retailer, builder, or tile fixer.

The problems of curvature and crazing which may materialize during storage owing to glaze-body mismatching, also belong to this group of characteristics.

c) In-service characteristics.

Ceramic tile defects are not the most important source of claims related to ceramic products. Claims are mainly due to the lack of suitability of a ceramic tile for a specific use, and installation defects (3)(4).

3. PRODUCT USE

Ceramic tiles, which were, until only a few years ago, almost exclusively used for tiling kitchens and bathrooms, have with technological advances in manufacturing, been steadily acquiring new and greater worth as building materials. Their field of application has spread to housing exteriors, particularly to public buildings, industrial environments, and urban decoration, among many other applications (5) (6).

Current ceramic product use includes:

- Residential interior tiling (kitchens, bathrooms, etc.)
- Exterior tiling (facades, urban applications, etc.)
- Residential interior paving
- Exterior paving (terraces, etc.)
- Tiling in public buildings (hospitals, schools, airports, etc.)
- Paving at industrial and commercial locations.
- Other tile installations (swimming pools, operating theatres, etc.)

Moreover, the builder, architect or final user who decides to install ceramic tiling, can choose from a vast range of ceramic products, which differ not only in size and dimensions, surface quality, surface colour and design, but also in physical and chemical characteristics.

In order for a ceramic product to be suitable for a specific use, it must fulfil a series of requirements that will be defined by consumer expectations.

To make it easier to arrange ceramic tile requirements according to their applications, a series of major ceramic tile uses can be defined, it being understood that for any different use, the associated requirements must be determined correspondingly.

In order to examine ceramic tile requirements, it is therefore necessary to simplify the number of possible ceramic tile uses, as well as the number of actual quality characteristics that are to be defined.

The following is an attempt to simplify ceramic tile uses (Figure 4):

TYPES OF PRODUCTS
- CERAMIC TILES FOR INTERIOR WALLS - CERAMIC TILES FOR EXTERIOR WALLS - CERAMIC TILES FOR INTERIOR PAVING OF RESIDENTIAL BUILDINGS - CERAMIC TILES FOR EXTERIOR PAVING OF RESIDENTIAL BUILDINGS - CERAMIC TILES FOR PAVING OF COLLECTIVE OR COMMERCIAL PREMISES - CERAMIC TILES FOR PAVING INDUSTRIAL PREMISES - CERAMIC TILES FOR OTHER USES

Figure 4.

The characteristics ceramic tiles must possess stem directly from service needs, so that the required characteristics, their importance and priority, must differ for each application.

Some cases involve special service conditions. For example, in the case of floor tiling for installations where water may be spilt or liquids could accumulate (swimming pool edges, industrial kitchens, car wash facilities, etc.), this paving must be highly slip resistant.

Furthermore, ceramic tile life depends on the suitable selection of material and particularly, its suitability for service conditions. Some aspects related to tile installation must also be taken into account, since these may to a greater or lesser extent also affect service requirements (Figure 5).

JUSTIFICATION OF THE MINIMUM SERVICE REQUIREMENTS
- CHARACTERISTICS THAT DEFINE CONSUMER EXPECTATIONS - NEEDS FOR FIXING AND PRODUCT USE - EXISTENCE OF PRODUCT STANDARDS - LIMITATIONS IN THE MANUFACTURING PROCESS - CHARACTERISTICS OF OTHER NON-CERAMIC MATERIALS

Figure 5.

WEATHER CONDITIONS. Especially important in exterior use, in geographic areas or on premises with significant changes in weather and in cold climates.

FUNCTION OF THE BUILDING. The function of the building will be a determining factor in cases where intense pedestrian traffic is involved. This requires ceramic tiles with high mechanical surface characteristics, and in the case of health facilities and schools, surfaces are needed that can easily be cleaned and disinfected.

LOCATION OF THE TILED AREA. Ceramic paving in outdoor areas, or at the entrance of housing units, for example, requires ceramic tile having high abrasion resistance. The surroundings of areas paved with ceramic tile can contribute abrasive particles, especially in geographic areas where granite is found, or can give rise to moisture or surface water. In this last case, ceramic tiles must have high slip resistance.

STRUCTURE AND NATURE OF THE BACKGROUND. In some cases the nature of the background materials is decisive. In the case of backgrounds of an elastic nature, tiling should be performed using small sizes.

It is therefore necessary, to define a product selection criterion according to product function. This criterion must be based on the kind of background surface that is to be tiled, as well as the nature of the actions or external agents to which the ceramic material will be subjected throughout its service life. Ceramic tile requirements must be based on both these considerations.

4. INDUSTRIAL PRODUCTION

4.1. CERAMIC TILE

Ceramic tiling possesses a series of characteristics that makes it stand out from other alternative materials. These characteristics can be generally summed up as follows:
Characteristics relative to impermeability, safety, well-being, maintenance in installations tiled with ceramic products (Figure 6).

CERAMIC TILE CHARACTERISTICS
RELATIVE TO IMPERMEABILITY
RELATIVE TO SAFETY - EASE OF CLEANING AND DISINFECTION - ANTI-SLIP - INCOMBUSTIBLE AND NON-HAZARDOUS IN THE CASE OF FIRE
RELATIVE TO WELL-BEING
RELATIVE TO MAINTENANCE OF BUILDINGS WITH CERAMIC TILING - CLEANABILITY - NO MAINTENANCE

Figure 6.

To be highlighted among the characteristics relative to the impermeability of these ceramic products are their moisture and water resistance. Ceramic surface finishes seal surfaces and withstand moisture well without deteriorating. Both glazed and unglazed tiles with low water absorption are also highly resistant to biological agents, which is indispensable in places where fungi or bacterial colonies can develop.

The most significant characteristics relating to safety are as follows: being incombustible and non-hazardous in the case of fire, asepsis and static stability. Ceramic tiles exhibit all these characteristics owing to the technological process they have undergone, as well as the raw materials from which they are made.

Among the characteristics related to well-being, the following deserve mention: thermal and acoustic insulation, and lack of a proper or acquired smell. Most of these characteristics do not solely depend upon the material involved, but are influenced by the whole set of materials required to install them in buildings. Some of these characteristics, however, do fully depend on ceramic tiles, such as absence of smell.

The characteristics relative to upkeep of premises with ceramic tiling include: Cleanability and no maintenance.

Correctly installed, non-porous, unglazed ceramic tiles, or porous tiles coated with a glaze or waterproof layer, are easily cleaned with a damp cloth, and if the surface is dirty or greasy, cleaning agents, such as detergents or bleaches can be used.

As a result of their electric equipotentiality, and the fact that they do not generate electrostatic charges, ceramic surface finishes do not capture electrically active ambient dust, and contribute to well-being.

The nature of ceramic surfaces prevents any kind of adhesion from arising, and when it does occur through some intermediary carrier (grease, etc.) it can easily be removed.

Ceramic tiling, except in the case of unglazed porous tile, needs no maintenance after installing, apart from normal cleaning operations.

4.2. THE MANUFACTURING PROCESS

The recent upgrading of the ceramic tile sector commenced at the start of the 80's and brought with it strong expansion of the sector. At that time, consumers were not aware of the quality issue, and were mostly concerned with finding a product that met their aesthetic or economic demands.

The situation has changed radically; at present, consumers find a wide range of ceramic products on the market, so that a product with ever stricter quality characteristics can be sought, whose characteristics respond to the expected performance and price.

It must also be said that ceramic tiles will not be more or less suited for a specific use in function of the raw materials or manufacturing process, but suitable ceramic tiles will be such that meet the requirements for specific uses. Thus, from the point of view of a product's technical quality in respect of its proposed use, the following terms are to be rejected: redware or whiteware products, pressed or extruded, glazed or unglazed products, or traditional twice-fired, fast twice-fired, porous single-fired products or porcelain tile (Figure 7).

MANUFACTURING PROCESS CHARACTERISTICS THAT DEFINE DIFFERENT TYPES OF PRODUCTS	
ACCORDING TO THE RAW MATERIAL	REDWARE PRODUCTS WHITEWARE PRODUCTS
ACCORDING TO THE SHAPING PROCESS	EXTRUDED PRODUCTS PRESSED PRODUCTS
WITH OR WITHOUT GLAZE APPLICATION	GLAZED PRODUCTS UNGLAZED PRODUCTS
ACCORDING TO THE FIRING PROCESS	TRADITIONAL TWICE-FIRED PRODUCTS FAST TWICE-FIRED PRODUCTS POROUS SINGLE-FIRED PRODUCTS PORCELAIN TILE

Figure 7.

5. CERAMIC TILE STANDARDS

Ceramic tiles are classified according to standard UNE 67-087 (EN 87). This European standard provides the generally used definitions, classification, characteristics and marking requirements of ceramic wall and floor tiles. Ceramic tiles also include mosaics, slabs, and pavers for industrial paving, and components for swimming pools, as well as the corresponding accessories (edge, corner and skirting tiles, beads and other pieces).

This standard applies exclusively to best quality commercial tile (first quality), unless otherwise specified in the relevant product standard. However, there is an agreement of the European Federation of Ceramic Tile Manufacturers, on a definition of the characteristics of different quality ceramic tile (7).

The European EN regulations divide ceramic tiles into various classes, laying down the characteristics to be controlled, and the tolerances for each. The limits of some characteristics have not been defined and are the result of agreement between manufacturer and purchaser.

The work involved in the European regulations for ceramic tile started in 1973, with the participation of the following countries: Italy, Spain, France, Germany, the United Kingdom, Belgium and Austria. The standards approved are listed in Table 1.

TABLE 1. EUROPEAN STANDARDS FOR CERAMIC FLOOR AND WALL TILES (EN)

BASIC STANDARD

EN 87 CERAMIC FLOOR AND WALL TILES. DEFINITIONS, CLASSIFICATION, CHARACTERISTICS AND MARKING.

PRODUCT STANDARDS

EN 121 EXTRUDED CERAMIC TILES WITH LOW WATER ABSORPTION ($E \leq 3\%$). GROUP AI.
 EN 186 EXTRUDED CERAMIC TILES WITH WATER ABSORPTION ($3\% < E \leq 6\%$). GROUP AIIa.
 EN 187 EXTRUDED CERAMIC TILES WITH WATER ABSORPTION ($6\% < E \leq 10\%$). GROUP AIIb.
 EN 188 EXTRUDED CERAMIC TILES WITH WATER ABSORPTION ($E > 10\%$). GROUP AIII.
 EN 176 DUST-PRESSED CERAMIC TILES WITH LOW WATER ABSORPTION ($E \leq 3\%$). GROUP BI.
 EN 177 DUST-PRESSED CERAMIC TILES WITH WATER ABSORPTION ($3\% < E \leq 6\%$). GROUP BIIa.
 EN 178 DUST-PRESSED CERAMIC TILES WITH WATER ABSORPTION ($6\% < E \leq 10\%$). GROUP BIIb.
 EN 159 DUST-PRESSED CERAMIC TILES WITH WATER ABSORPTION ($E > 10\%$). GROUP BIII.

STANDARDS FOR TESTING, SAMPLING AND BASIS FOR ACCEPTANCE.

EN 98 DETERMINATION OF DIMENSIONS AND SURFACE QUALITY.
 EN 99 DETERMINATION OF WATER ABSORPTION.
 EN 100 DETERMINATION OF MODULUS OF RUPTURE.
 EN 101 DETERMINATION OF SCRATCH HARDNESS OF SURFACE ACCORDING TO MOHS.
 EN 102 DETERMINATION OF RESISTANCE TO DEEP ABRASION. UNGLAZED TILES.
 EN 154 DETERMINATION OF RESISTANCE TO SURFACE ABRASION. GLAZED TILES.
 EN 103 DETERMINATION OF LINEAR THERMAL EXPANSION.
 EN 104 DETERMINATION OF RESISTANCE TO THERMAL SHOCK.
 EN 105 DETERMINATION OF CRAZING RESISTANCE. GLAZED TILES.
 EN 202 DETERMINATION OF FROST RESISTANCE.
 EN 155 DETERMINATION OF MOISTURE EXPANSION USING BOILING WATER. UNGLAZED TILES.
 EN 106 DETERMINATION OF CHEMICAL RESISTANCE. UNGLAZED TILES.
 EN 122 DETERMINATION OF CHEMICAL RESISTANCE. GLAZED TILES.
 EN 163 CERAMIC TILES. SAMPLING AND BASIS FOR ACCEPTANCE.

At that time, the manufacturing process was that of traditional twice firing with slow firing cycles, and at that period, porous ceramic products were assimilated as materials for use in wall tiling (which was the major use), and in some cases as interior floor coverings inside the home. The regulations therefore implicitly considered ceramic tile characteristics, using a classification that depended on water absorption, which suggested, that ceramic tiles with a high water absorption capability (greater than 10%), were recommendable for interior wall tiling, and tiles with a limited water absorption capability were suited for exterior and interior paving and exterior wall tiling (8).

The body of the European standards was prepared in accordance with the technical conditions, the testing methods and major uses of these ceramic products, of the time. As the manufacturing process was further perfected, and ceramic tile uses diversified, there were advances in ceramic product adaptation to service conditions, with corresponding advances in test methods and studies on durability of ceramic tiles under specific service conditions.

One such advance has been the ISO standard for ceramic tiles, and together with this, all the specific requirements that individual companies apply to assess their products for specific uses (Table2) (9).

TABLE 2. INTERNATIONAL STANDARDS FOR CERAMIC FLOOR AND WALL TILES (ISO)

GENERAL STANDARD

ISO 13006	CERAMIC TILES. DEFINITIONS. CLASSIFICATION, CHARACTERISTICS AND MARKING.
ISO 10545/1	SAMPLING AND BASIS FOR ACCEPTANCE.
ISO 10545/2	DETERMINATION OF DIMENSIONS AND SURFACE QUALITY.
ISO 10545/3	DETERMINATION OF WATER ABSORPTION, APPARENT POROSITY, APPARENT RELATIVE DENSITY AND BULK DENSITY.
ISO 10545/4	DETERMINATION OF THE MODULUS OF RUPTURE AND BREAKING STRENGTH.
ISO 10545/5	DETERMINATION OF IMPACT RESISTANCE BY MEASUREMENT OF THE COEFFICIENT OF RESTITUTION.
ISO 10545/6	DETERMINATION OF RESISTANCE TO DEEP ABRASION. UNGLAZED TILES.
ISO 10545/7	DETERMINATION OF RESISTANCE TO SURFACE ABRASION. GLAZED TILES.
ISO 10545/8	DETERMINATION OF LINEAR THERMAL EXPANSION.
ISO 10545/9	DETERMINATION OF RESISTANCE TO THERMAL SHOCK.
ISO 10545/10	DETERMINATION OF MOISTURE EXPANSION.
ISO 10545/11	DETERMINATION OF CRAZING RESISTANCE. GLAZED TILES.
ISO 10545/12	DETERMINATION OF FROST RESISTANCE.
ISO 10545/13	DETERMINATION OF CHEMICAL RESISTANCE.
ISO 10545/14	DETERMINATION OF STAIN RESISTANCE.
ISO 10545/15	EXTRACTION OF CADMIUM AND LEAD FROM GLAZED TILES.
ISO 10545/16	DETERMINATION OF COLOUR DIFFERENCES.
ISO 10545/17	DETERMINATION OF THE COEFFICIENT OF FRICTION.

At present, any ceramic tile will be suitable for a specific use if a series of service requirements are met. Therefore, as stated above, the environment of the installation must also be taken into account in choosing ceramic wall or floor tiles, as the environment defines some of the requirements these materials must comply with.

Figures 8 and 9 detail the respective European EN and ISO regulations, in respect of their adaptation to service requirements.

ADAPTATION OF CERAMIC TILE STANDARDS TO SERVICE REQUIREMENTS	
EUROPEAN STANDARDS (EN) THAT DO NOT ADAPT TO REQUIREMENTS FOR SPECIFIC USES (AS THEIR CLASSIFICATION AND VARIABLES ARE LINKED TO MANUFACTURING PROCESS PARAMETERS)	
-	BASIC STANDARD (EN 87)
-	PRODUCT STANDARDS (EN 121, EN 186, EN 187, EN 188, EN 176, EN 177, EN 178, EN 159)
-	TEST STANDARD (EN 98) DETERMINATION OF DIMENSIONS AND SURFACE QUALITY
-	TEST STANDARD (EN 100) DETERMINATION OF THE MODULUS OF RUPTURE
EUROPEAN STANDARDS (EN) THAT DO NOT ADAPT TO REQUIREMENTS FOR SPECIFIC USES (AS THE METHODS DIFFER SUBSTANTIALLY FROM ACTUAL ACTIONS OR ARE QUITE UNDEMANDING)	
-	TEST STANDARD (EN 102) DETERMINATION OF RESISTANCE TO DEEP ABRASION. UNGLAZED TILES.
-	TEST STANDARD (EN 154) DETERMINATION OF RESISTANCE TO SURFACE ABRASION. GLAZED TILES
-	TEST STANDARD (EN 105) DETERMINATION OF CRAZING RESISTANCE
-	TEST STANDARD (EN 202) DETERMINATION OF FROST RESISTANCE
-	TEST STANDARD (EN 101) DETERMINATION OF SCRATCH RESISTANCE OF SURFACE ACCORDING TO MOHS

Figure 8.

ADAPTATION OF ISO STANDARDS FOR CERAMIC TILES TO SERVICE REQUIREMENTS	
ISO STANDARDS THAT DO NOT ADAPT TO REQUIREMENTS FOR SPECIFIC USES (AS THEIR CLASSIFICATION AND VARIABLES ARE LINKED TO MANUFACTURING PROCESS PARAMETERS)	
ISO 13006	DEFINITIONS, CLASSIFICATION, CHARACTERISTICS, REQUIREMENTS AND MARKING.
ISO 10545 Part 2	DETERMINATION OF DIMENSIONS AND SURFACE QUALITY.
ISO STANDARDS THAT DO NOT ADAPT TO REQUIREMENTS FOR SPECIFIC USES (AS THE METHODS DIFFER SUBSTANTIALLY FROM THE ACTUAL ACTIONS OR ARE QUITE UNDEMANDING)	
ISO 10545 Part 5	DETERMINATION OF IMPACT RESISTANCE BY THE MEASUREMENT OF THE COEFFICIENT OF RESTITUTION.
ISO 10545 Part 6	DETERMINATION OF RESISTANCE TO DEEP ABRASION. UNGLAZED TILES
ISO 10545 Part 7	DETERMINATION OF RESISTANCE TO SURFACE ABRASION. GLAZED TILES.
ISO 10545 Part 11	DETERMINATION OF CRAZING RESISTANCE. GLAZED TILES
ISO STANDARDS THAT ADAPT TO REQUIREMENTS FOR SPECIFIC USES	
ISO 10545 Part 4	DETERMINATION OF THE MODULUS OF RUPTURE AND BREAKING STRENGTH.
ISO 10545 Part 10	DETERMINATION OF MOISTURE EXPANSION.
ISO 10545 Part 12	DETERMINATION OF FROST RESISTANCE.
ISO 10545 Part 13	DETERMINATION OF CHEMICAL RESISTANCE.
ISO 10545 Part 14	DETERMINATION OF STAIN RESISTANCE.
ISO 10545 Part 17	DETERMINATION OF THE COEFFICIENT OF FRICTION.

Figure 9.

5.1. EUROPEAN STANDARDS (EN)

There is, first of all, a series of standards that do not adapt to the requirements for specific uses, since the classification and the variables are related to manufacturing process parameters.

Basic standard (EN 87). This standard classifies ceramic tiles in function of their water absorption capability, and not in terms of possible use, suggesting that materials having a lower water absorption capability will exhibit more mechanical characteristics, which is also the case with the product standards (EN 121, EN 186, EN 187, EN 188, EN 176, EN 177, EN 178 and EN 159).

Test standards.

- Determination of dimensions and surface quality (EN 98). In this standard, the defined dimensional tolerances are in function of tile size. Therefore, larger tile sizes have greater dimensional deviations, which does not match service requirements.
- Determination of the modulus of rupture (EN 100) relates the value of bending strength to the thickness of the ceramic tile. Thus, the smaller the thickness, the greater is the bending strength value defined by this standard, which means at least some possible confusion for the tile fixer or the final user, and a problem when it comes to any intent to adapt the standard to service requirements.

There is another set of European standards that do not adapt to the requirements for specific uses, as the methods for determination differ substantially from actual actions, and whose results cannot really be compared to results obtained under service conditions or are quite undemanding. This group includes the following regulations:

Determination of resistance to deep abrasion. Unglazed tiles (EN 102). The method determines abrasion resistance in unglazed ceramic tiles by measuring the length of the groove produced by a rotating disc under set conditions, using alumina as abrasive material. The method of determination does not reproduce the real action of surface wear in unglazed ceramic tiles, and it does not appear easy to establish a correlation between the results of abrasion by a rotating disc, and the actual abrasion arising as a result of pedestrian traffic.

Determination of resistance to surface abrasion. Glazed tiles (EN 154). The method determines the resistance to surface abrasion, by rotation of an abrasive load over the glazed tile surface, and visually assessing the abraded surface. The method of determination does not reproduce the real action of surface wear in glazed ceramic tiles (10) (11) (12), while visual appraisal is a subjective quantification of the changes the ceramic tile undergoes (gloss, colour, roughness, stainable surface, etc.)(13)(14)(15).

Determination of crazing resistance (EN 105). Crazing resistance is determined by subjecting whole tiles to water vapour, at high pressure in an autoclave (5 kg/cm² for one hour), and then examining them after applying a dye to the glazed face. The pieces inside the autoclave curve easily, which does not happen in reality when tiles are installed, and the test is observed to be quite undemanding, with numerous cases of real crazing being detected in installed wall tiles that had passed this crazing resistance test.

Determination of frost resistance (EN 202). The method involves subjecting tiles that have been impregnated with water, to cycles of +15°C to -15°C, with all the tile sides exposed to freezing, for 50 freeze-thaw cycles. The standard method for impregnating tiles with water is by progressive impregnation by capillarity, which is not a rigorous method, and cases have been detected of ceramic tiles breaking as a result of frost, on exposing the tiles, which had passed this test, to the actual ambient.

Determination of surface scratch hardness according to Mohs (EN 101). The method involves rubbing certain minerals of known hardness, by hand, across a tile surface. To be highlighted are: the problematic involved in performing the test, the inexistence of standard minerals, the difficulty involved in scratching a tile surface with a constant, even pressure, and the lack of precision with regard to the viewing array for examining possible lines (distance, light source characteristics, viewing equipment, etc.). Therefore, the method exhibits a wide scattering of interpretations and results, which has been why it has been deleted from the ISO TC 189 Ceramic Tiles regulations.

5.2. INTERNATIONAL STANDARDS (ISO)

As is the case of the European standards, there is first of all a series of standards that do not adapt to the requirements for specific uses, as the classification and the variables are related to manufacturing process parameters.

ISO 13006. Definitions, classification, requirements and marking. The standard classifies ceramic tiles in function of their water absorption capability and not in terms of possible use.

ISO 10545 Part 2. Dimensions and surface quality. As in the European standard, the dimensional tolerances set in this standard are a function of ceramic tile size, so that with larger ceramic tile sizes the deviation allowed increases, which does not match service requirements.

There is another set of ISO standards that do not adapt to requirements for specific uses, as the determination methods substantially differ from real actions, and their results can hardly be compared with those which would be obtained in service conditions, or are not very rigorous at all. This group includes the following standards:

ISO 10545 Part 5. Determination of impact resistance by measuring the coefficient of restitution. It is based on the rebound of a steel ball of 19 mm diameter, which is dropped from a height of 120 cm onto a tile set in a mortar background. The method does not measure the possible damage that may arise in the ceramic tiles after impact.

ISO 10545 Part 6. Determination of deep abrasion. Unglazed tiles. It resembles the European standard, with some slight variations. As in the foregoing case, the method of determination does not reproduce the real action of surface wear in unglazed ceramic tiles, and it does appear easy to establish a correlation between the results of abrading with a rotating disc and real abrasion as a result of pedestrian traffic.

ISO 10545 Part 7. Determination of resistance to surface abrasion. Glazed tiles. It is similar to the European standard. As in that standard, the method of determination does not reproduce the real action of surface wear in glazed ceramic tiles, and there is a subjective visual examination to quantify the changes in the ceramic tile (gloss, colour, roughness, stainable surface, etc.). It does, however, introduce class V, which besides requiring that no visible wear be left as a result of abrasion at 12000 revolutions, requires that the tile resist the stain test, which certainly is a significant improvement.

ISO 10545 Part 11. Determination of crazing resistance. It resembles the European standard, and as in this case, the pieces inside the autoclave continue releasing stress on curving, which does not take place in actual fact when tiles are installed. Although it doubles dwell time of the pieces in the autoclave, the test continues to be rather undemanding.

There is another group of ISO standards which are suited to the requirements for specific purposes, as the methods of determination are more rigorous than in the case of the European regulations, and do not depend on manufacturing process parameters. The following standards are included in this group:

ISO 10545 Part 4. Determination of the modulus of rupture and breaking strength. It introduces a breaking strength, which is independent of the thickness of the ceramic tile, although the standard continues to give values for the modulus of rupture, which, as has been mentioned, depends on the thickness of the ceramic tile. This can all lead to confusion in using breaking strength or the modulus of rupture.

ISO 10545 Part 12. Determination of frost resistance. With regard to the European standard, the method of tile impregnation by evacuation is now the only impregnation method, and the standard raises the number of test cycles to 100 freeze-thaw cycles.

ISO 10545 Part 13. Determination of chemical resistance. This is a single standard for glazed and unglazed tiles and defines different concentrations according to use.

ISO 10545 Part 14. Determination of stain resistance. It is a step forward with regard to the European regulation, and uses a series of more common reagents.

ISO 10545 Part 17. Determination of the coefficient of friction. It defines a very important floor tile characteristic from a safety point of view, and incorporates the measurement of a dynamic coefficient of friction (wet and dry) (16) and a static coefficient of friction.

The ISO standards, as mentioned above, have discarded the determination of surface scratch hardness according Mohs.

The ISO regulations represent a significant advance from the point of view of their adaptation to service requirements, which is why it has also been preferred to incorporate them whenever possible, in setting the requirements.

6. REQUIREMENTS OF CERAMIC TILES ACCORDING TO USE

Although the justification for the requirements of ceramic tiles in use, can involve a series of possibilities (Figure 5), their definition can only be based on the characteristics that define consumer expectations and the needs of product installation and use, using available product standards and standard tests whenever feasible.

Table 3 details the relationship between the ceramic tile characteristics that define consumer expectations and the requirements for use. The tolerances of the quality characteristics should be defined for each specific use.

In no case, in defining these requirements, have any limitations of the manufacturing process been taken into account, which are at present usually lower than what is needed for use. Nor have less favourable characteristics of other non-ceramic products for similar applications been taken into account.

Specifying certain requirements of ceramic tiles for specific uses is no novelty, as stated at the outset. Many companies perform specific tests that are independent of current standards, or anticipate these in defining their requirements.

TABLE 3. RELATIONSHIP BETWEEN CERAMIC TILE CHARACTERISTICS THAT DEFINE CONSUMER EXPECTATIONS AND SERVICE REQUIREMENTS.		
PERCEIVABLE CHARACTERISTICS PRIOR TO USE, DECISIVE TO THE PURCHASE	DIMENSIONS (SHAPE, SIZE), SURFACE APPEARANCE (COLOUR, GLOSS, DESIGN, ROUGHNESS, FRICTION, ETC.)	- AESTHETIC AND DECORATIVE CHARACTERISTICS - DIMENSIONS AND SURFACE QUALITY (ISO 10545/2) - DETERMINATION OF COLOUR DIFFERENCES (ISO 10545/16) - DETERMINATION OF THE COEFFICIENT OF FRICTION (ISO 10545/17)
CHARACTERISTICS RELATING TO FIXING AND STORAGE (APPRECIABLE FOR THE TILE FIXER AND/OR RETAILER, BUT NOT APPRECIABLE FOR THE FINAL USER)	EASE OF HANDLING (WEIGHT, SHAPE, SIZE, THICKNESS, PACKAGING, NUMBER OF COMBINABLE PIECES, ETC.) FIXING YIELD (SHAPE, COMBINABILITY) BONDING TO BACKGROUND, STABILITY IN STORAGE (CURVATURE, CRAZING, ETC.)	- CHARACTERISTICS RELATED WITH INSTALLING AND STORING TILE - DETERMINATION OF WATER ABSORPTION, APPARENT POROSITY, APPARENT RELATIVE DENSITY AND BULK DENSITY (ISO 10545/3) - DETERMINATION OF CRAZING RESISTANCE, GLAZED TILES. (ISO 10545/11)
SERVICE CHARACTERISTICS (PERCEIVABLE FOR THE FINAL USER, BUT UNKNOWN WHEN PURCHASED)	IMPAIRED APPEARANCE (BREAKING, FLAKING, CRAZING, INTERNAL OR EXTERNAL DIRT RETENTION, CHANGES IN COLOUR, GLOSS, OR LOSS OF SURFACE QUALITY)	- DETERMINATION OF THE MODULUS OF RUPTURE AND BREAKING STRENGTH (ISO 10545/4) - DETERMINATION OF IMPACT RESISTANCE BY MEASUREMENT OF THE COEFFICIENT OF RESTITUTION (ISO 10545/5) - DETERMINATION OF RESISTANCE TO DEEP ABRASION (ISO 10545/6) - DETERMINATION OF RESISTANCE TO SURFACE ABRASION (ISO 10545/7) - DETERMINATION OF MOISTURE EXPANSION (ISO 10545/10) - DETERMINATION OF CRAZING RESISTANCE, GLAZED TILES. (ISO 10545/11) - DETERMINATION OF FROST RESISTANCE (ISO 10545/12) - DETERMINATION OF CHEMICAL RESISTANCE (ISO 10545/13) - DETERMINATION OF STAIN RESISTANCE (ISO 10545/14)
	RELATED TO SAFETY (FRACTURES, OR INJURIES, SLIPPERY SURFACE, POSSIBLE RELEASE OF HARMFUL ELEMENTS OR COMPOUNDS)	- DETERMINATION OF THE COEFFICIENT OF FRICTION (ISO 10545/17) - DETERMINATION OF FROST RESISTANCE (ISO 10545/12) - DETERMINATION OF MOISTURE EXPANSION (ISO 10545/10)
	RELATED TO HYGIENE OR DISINFECTION (ADHESION, POROSITY, POSSIBLE RELEASE OF DUST)	- DETERMINATION OF WATER ABSORPTION, APPARENT POROSITY, APPARENT RELATIVE DENSITY AND BULK DENSITY (ISO 10545/3) - DETERMINATION OF CHEMICAL RESISTANCE (ISO 10545/13) - DETERMINATION OF STAIN RESISTANCE (ISO 10545/14)

The following are a few examples:

- Determination of the abrasion resistance of glazed tile, with a stain resistance test after abrading, whose use led to its incorporation in ISO regulations.
- Determination of the durability of ceramic tiles with regard to wear by abrasion.
- Determination of crazing resistance with repetitive testing at high pressure (3 cycles at 10 kg/cm²).
- Determination of the durability of ceramic tiles with regard to frost in real conditions.
- Determination of resistance to chemical agents and staining, by means of tests with specific agents.

Ceramic tile requirements must undergo continuous changes in order to better adapt ceramic tiles to consumer expectations, and to include novel uses with specific constraints. They must also be dynamic, owing to the on-going improvement in test methods of quality characteristics.

The ultimate striving is to have available a classification of a company's current products for their possible uses, or be able to provide the clearest possible understanding of product adaptability to new specific uses (commercial centres, computer rooms, tunnel lining, etc.).

Taking into account the above, and the fact that many of the requirements of coverings in construction, are met by ceramic tiles, a series of ceramic tile requirements for specific purposes has been defined. These are shown in Figs. 10 to 12.

It may be observed that the ISO standard was used to quantify the requirements, although in some cases the standards are not as close as desired to service requirements. This is a further part of the on-going work that must be carried out in order to get closer to service requirements and consumer expectations.

The values of the requirements were obtained by surveys of ceramic product claims, and whenever possible by durability studies, which is the great study gap as far as these ceramic products are concerned.

DIMENSIONAL CHARACTERISTICS CERAMIC FLOOR TILES	Suggested values	
	Jointless installation	Installation with joints
LENGTH AND WIDTH * Permitted deviation of the mean size of each tile with regard to: - manufacture size - sample tile mean size THICKNESS * Permitted deviation of the mean thickness of each tile with regard to manufacture size STRAIGHTNESS OF EDGES * Maximum deviation of straightness RECTANGULARITY * Maximum deviation of rectangularity SURFACE FLATNESS * Maximum deviation of flatness - central curvature related to the diagonal - edge curvature - warpage related to the diagonal	$\pm 0.6\%$ (< 2.4 mm) $\pm 0.5\%$ (1.5 mm) $\pm 5\%$ $\pm 0.5\%$ (< 1.5 mm) $\pm 0.6\%$ (< 1.5mm) $\pm 0.5\%$ (< 2mm) $\pm 0.5\%$ (< 2mm) $\pm 0.5\%$ (< 2mm)	$\pm 2\%$ (< 4 mm) $\pm 1.5\%$ $\pm 10\%$ $\pm 1\%$ (< 4 mm) $\pm 1\%$ (< 4 mm) $\pm 1.5\%$ (< 6 mm) $\pm 1.5\%$ (< 6 mm) $\pm 1.5\%$ (< 6 mm)
SURFACE QUALITY	A minimum of 95% of tiles examined at 1 m with 300 lux, must be without defects	

Figure 10.

DIMENSIONAL CHARACTERISTICS CERAMIC WALL TILES	Suggested values	
	Jointless installation	Installation with joints
LENGTH AND WIDTH * Permitted deviation of the mean size of each tile with regard to: - manufacture size - sample tile mean size THICKNESS * Permitted deviation of the mean thickness of each tile with regard to manufacture size STRAIGHTNESS OF EDGES * Maximum deviation of straightness RECTANGULARITY * Maximum deviation of rectangularity SURFACE FLATNESS * Maximum deviation of flatness - central curvature related to the diagonal - edge curvature - warpage related to the diagonal	$\pm 0.5\%$ (< 1.5 mm) $\pm 0.3\%$ $\pm 10\%$ $\pm 0.3\%$ (< 1.2 mm) $\pm 0.5\%$ (< 1.5 mm) $+0.5/-0.3\%$ (< 2 mm) $+0.5/-0.3\%$ (< 2 mm) $\pm 0.5\%$ (< 2 mm)	$\pm 2\%$ (< 4 mm) $\pm 1.5\%$ $\pm 10\%$ $\pm 0.6\%$ (< 2.4 mm) $\pm 1\%$ (< 4 mm) $\pm 1.5\%$ (< 6 mm) $\pm 1.5\%$ (< 6 mm) $\pm 1.5\%$ (< 6 mm)
SURFACE QUALITY	A minimum of 95% of tiles examined at 1 m with 300 lux, must be without defects	

Figure 11.

CERAMIC TILE REQUIREMENTS						
CHARACTERISTICS		SUGGESTED VALUE				
		PIE	SIR	SER	SLC	SLI
DETERMINATION OF BREAKING STRENGTH (N) ISO 10545/4. MINIMUM		450	900	900	900	2000
DETERMINATION OF RESISTANCE TO DEEP ABRASION.(mm ³) UNGLAZED TILES ISO 10545/6. MAXIMUM		---	2365	2365	649	393
DETERMINATION OF RESISTANCE TO ABRASION. GLAZED TILES. ISO 10545/7. LOWEST CLASS		---	(1)	III	IV	IV
DETERMINATION OF MOISTURE EXPANSION.(mm/m) ISO 10545/10.		0.6	0.6	0.6	0.6	0.6
DETERMINATION OF CRAZING RESISTANCE. ISO 10545/11 ADVISABLE 3 CYCLES 10 kg/cm ²		R R	R R	R R	R R	R R
DETERMINATION OF FROST RESISTANCE. ISO 10545/12. (REQUIRED ACCORDING TO CLIMATE)		R(2)	---	R	R	R
DETERMINATION OF RESISTANCE TO CLEANING AGENTS. ISO 10545/13 LOWEST CLASS		A	A	A	A	A
DETERMINATION OF CHEMICAL RESISTANCE. LOW CONCENTRATE REAGENTS. ISO 10545/13 LOWEST CLASS		B	B	B	B	B
DETERMINATION OF STAIN RESISTANCE. ISO 10545/14 LOWEST CLASS		3	3	3	3	3
DETERMINATION OF THE COEFFICIENT OF FRICTION. ISO 10545/17 MINIMUM		---	0.4	0.4	0.4	0.4
PIE	TILES FOR INTERIOR OR EXTERIOR WALLS					
SIR	TILES FOR INTERIOR PAVING OF RESIDENTIAL BUILDINGS					
SER	TILES FOR EXTERIOR PAVING OF RESIDENTIAL BUILDINGS					
SLC	CERAMIC TILES FOR PAVING OF COLLECTIVE OR COMMERCIAL PREMISES					
SLI	CERAMIC TILES FOR PAVING INDUSTRIAL PREMISES					
R	RESISTANT					
A,B,3	ISO STANDARD CLASSES FOR RESISTANCE TO CLEANING AGENTS, CHEMICAL AGENTS, AND STAINS					
(1)	CLASS I. BATHROOMS CLASS II. BEDROOMS CLASS III. KITCHENS AND HIGHLY TRANSITED AREAS					
(2)	EXCLUSIVELY FOR EXTERIOR WALLS					
---	NO REQUIREMENTS					

Figure 12.

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