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ScienceDirect
Journal of the European Ceramic Society 27 (2007) 1607–1613
www.elsevier.com/locate/jeurceramsoc

Ceramic tiles: Above and beyond traditional applications

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Available online 23 June 2006

Abstract

At present ceramic tiles are already being marketed with characteristics and performance features that make them products whose applications go far beyond traditional tile uses. These are not just future possibilities: their industrial and commercial reality already makes them immediately serviceable in multiple environments. And this is precisely the key concept in these new tile applications: their features make them useable for wholly different functions – functions till now reserved for other products – or, in certain cases, for entirely novel functions. In addition, the functionalities involved are destined to improve aspects directly related to the quality of life, conditions of habitability or, for instance, to using such a vital natural source of energy as solar radiation. It should, therefore, be stressed that these new generations of ceramic tiles are to be considered part of the range of architectural elements for both external and internal uses, since, as the following will show, they provide the surfaces they clad with a broad spectrum of properties and functions without detriment to the aesthetic qualities, always so characteristic, of ceramic tile.

To illustrate the above, the present paper describes three new families of ceramic products. These groups of products are conceptually different and many-sided, which makes them serviceable as functional elements in different contexts.

Keywords: TiO_2; Traditional ceramics; Functional applications; Sensors; Electrical properties

1. Introduction

Ceramic tiles are no strangers to the trend witnessed in recent years in numerous products of the so-called traditional industrial sectors: the search for new uses that enable extending their customary market.[2,4–7] Indeed, this should come as no surprise, as the characteristics of ceramic materials allow multiple applications. An example in this sense is technical ceramics: these have for years been used in applications associated with high technology, given their optimal technical performance features—particularly in comparison with other materials like metals, which had long been the standard materials in this context. Many examples could be cited to illustrate the foregoing. Suffice it in this respect just to mention ceramic components for engines, ceramic coatings for drilling equipment, turbine blades, ceramic membranes,[23] supports for integrated circuits, etc.

Yet although tiles are also ceramic products, they do not enjoy this technological aureole and the high profile of being a product of the future, which characterise the above applications and the ceramic materials involved. Thus, it is precisely the purpose of this paper to set out the real possibilities that these products have at present, as elements that contribute new properties in different spheres.[16,24] Nor should it be forgotten in this sense that ceramic tiles have already been used before for non-conventional purposes in a high-tech application, as outer cladding for space shuttles. There is hence no reason to believe tiles might not equally be used in other novel applications, albeit perhaps less strikingly from the standpoint of the media.

This paper deals specifically with the possibility of using ceramic tiles as supports in which to integrate elements such as photovoltaic cells, presence sensors for detecting movement or activating other devices (opening, locking systems, etc.), heat sensors for fire detection, electric switches, etc. Other applications already in development are also discussed, relating to the use of glaze coatings with self-cleaning, hygienic, air-regenerating, bactericidal, anti-grease or anti-misting properties, some of which have already been implemented in other branches, like the glass sector, and whose implementation is currently in progress in the ceramic sector. All this, without forgetting ceramic coatings with electricity-conducting or insulating properties, etc.

In conclusion, it is attempted to provide a brief overview of a great number of new avenues that are opening up for the use of a product – till quite recently considered traditional, with little or no relation at all to new needs and tendencies – as a

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doi:10.1016/j.jeurceramsoc.2006.04.146

constituent element of future internal and external architectural structures.

2. Tiles with functional coatings

These tiles have first undergone the usual manufacturing process; products are then deposited and fixed on the tile surface, which supply it with various properties that convert these tiles into functional items. Particularly noteworthy in this sense are two types of coatings of singular interest, which have already been commercially implemented:

2.1. Coatings with photocatalytic properties

Coatings with photocatalytic properties, i.e. activatable by UV radiation. These yield surfaces with a series of special characteristics, based on the ability of such coatings to destroy organic matter (in a solid, liquid or gaseous state) that settles on or brushes the surface,[10,15] and to heighten surface wettability and encourage sliding of the water that is deposited, artificially or naturally, on these surfaces.

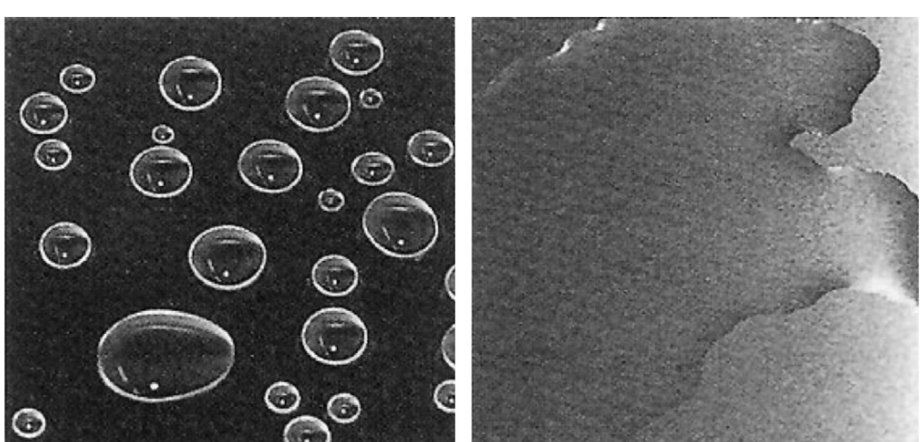
The extremely thin coating is transparent and colourless, and thus does not affect the aesthetic finish of the underlying glaze, which holds its aesthetic qualities. In addition, given its inorganic nature, the coating is non-combustible[8] and resistant to the usual cleaning agents. As indicated above, coating properties are activated by UV radiation, which produces a series of modifications in the coating's internal electron structure,[22,26] while leaving its appearance and macroscopic technical surface characteristics (hardness, chemical resistance, etc.) unaffected. This UV radiation is present in daylight (even without direct sunlight) and, partially, in certain artificial light sources. This type of coating is therefore particularly appropriate for outdoor and indoor areas exposed to sufficient natural light, or with appropriate artificial lighting sources.

The activator effect generated in the surface does not disappear immediately when the radiation ceases, but lasts for a sufficiently long time (longer than night-time) to ensure its effectiveness. This effectiveness is based on the combination of two properties mentioned previously: the destruction of organic matter and wettability. The result is a series of functionalities of wide interest and applicability, which include:

Source: FUJISHIMA, A. et al. *TiO_2 Photocatalysis. Fundamentals and applications*. Japan, 2001

Fig. 2. Anti-condensation effect of a photocatalytic coating.

- *Self-cleaning effect or cleanability*. The fact that water spreads particularly well on these surfaces encourages the water to sweep along any material that might be found on such surfaces and could soil these. When exposed external surfaces are involved, the rain itself can act as a cleaner,[8] or water can otherwise be supplied artificially; however, in either case, dirt detachability from these surfaces always far exceeds that displayed by conventional ceramic surfaces. This affinity for water also facilitates the removal of greasy deposits that could adhere to these surfaces (a typical situation in kitchens), thus, reducing the need to use more or less aggressive or toxic degreasing cleaners[8] (Fig. 1).
- *Anti-fogging effect*. Since, the applied coating enhances surface wettability, any arising water condensation does not lead to the formation of water droplets that fog the surface and which, when they dry, leave dirty residues (a particularly important phenomenon in bathrooms); instead, the condensed water runs off the surface, leaving it perfectly clean (Fig. 2).



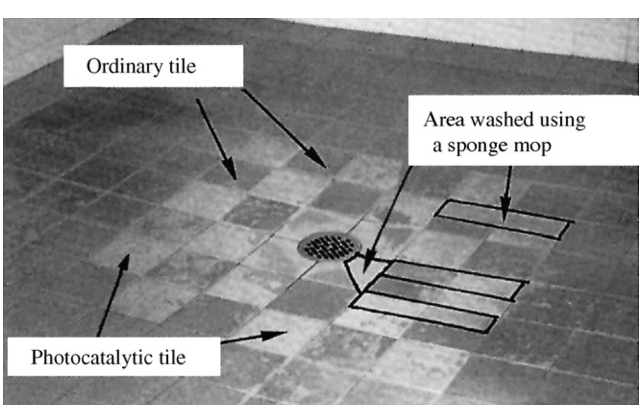
Source: FUJISHIMA, A.; HASHIMOTO, K.; WATANABE, T. *TiO_2 photocatalysis: fundamentals and applications*. Tokyo: BKC, 2001.

Fig. 1. Hydrophillic effect of a photocatalytic coating.

The same effect is equally of interest in exteriors, where it serves to keep raindrops from clinging to the surface and spoiling the surface appearance.

- *Sterilising effect*. The destruction of the organic matter that may be generated or deposited on this type of surface has an extremely useful, twofold effect in terms of hygiene and comfort. On the one hand, in situations that encourage microorganism formation (bacteria, mould, lichens, moss, fungi, etc.), microorganism growth and reproduction are inhibited by contact with these coatings which, thus, lead to the destruction of the microorganisms. This is of particular interest in building areas where strict hygiene is required (operating rooms, hospitals, catering establishments, etc.), and in internal or external domains exposed to high humidity, swimming pool surrounds, showers, locker rooms and similar facilities. On the other hand, on such surfaces, for the reasons set out above, the running water occurring in these environments can easily sweep along the microorganism residues, leaving the surfaces clean and hygienic. In addition, these features also enable addressing a very important problem in flooring (e.g. in public domains): the risk of slipping accidents owing to the presence of organic matter on these surfaces, a risk that can thus be diminished (Fig. 3). A further application of this same functionality relates to the removal of tobacco stains that impregnate walls, stain surfaces, and leave an obnoxious smell.
- *Air purification*. When air is brought into continuous contact with the photocatalytic surfaces by means of an appropriate air recirculation system, the air-borne microorganisms responsible for bad smells and foul atmospheres, etc. are neutralized, producing a more comfortable ambient for family or professional life.

This technology, initially developed in Japan in the 1970s, is currently widespread and has been adapted to different substrates,[3,14,19–21] not just ceramics,[25] while the technology involved has been the focus of innumerable patents and utility models.[18] At present, several firms market ceramic tiles with these coatings.



Source: FUJISHIMA, A. et al. TiO_2 *Photocatalysis. Fundamentals and applications*. Japan, 2001.

Fig. 3. Sterilising effect of a photocatalytic coating.

Source: BASF - Wood surface repels water droplets. 2002

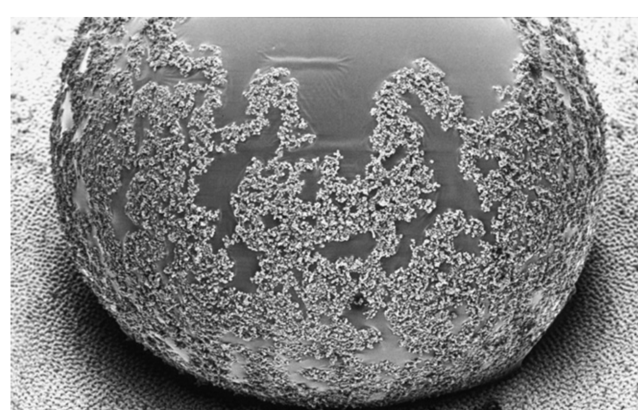
Fig. 4. Drop formation on a hydrophobic surface.

2.2. Coatings with hydrophobic properties

Coatings with hydrophobic properties, which notably increase the angle of contact between the surface of the piece and the impinging water (Fig. 4), consequently favouring the formation of drops to which the existing dust particles adhere (Fig. 5). The drops slide easily across this surface, dragging along the dirt and helping to keep the fair face free of inert material (dust, dry vegetal residues, etc.).

This effect resembles what happens on the leaves of the lotus plant, which are a striking example in nature of these types of surfaces. The effect stems from the rough morphology of these leaf surfaces, which, together with the existence of small wax crystals, makes them highly hydrophobic.[1]

The hydrophobic coatings used on glazed surfaces consist of a combination of organic and inorganic materials of nanometre particle size, which reduce surface tension, thus, contributing the above properties to the surface onto which they are applied. Several companies currently market these types of products. In fact, the application of such products onto different substrates,



Source: BASF - The lotus effect keeps the leaf surface clean. 2002

Fig. 5. Drop of water with dirt particles on a hydrophobic coating.

such as glazed roofing tiles and ceramic tiles, has even led to the formation recently of an industrial consortium on a European scale.

3. Ambient humidity-regulating tiles

A product developed and marketed by INAX CORPORATION (http://www.inax.co.jp). The product features a closely controlled fine apparent porosity which, together with the specific nature of the composition, enables it to exchange moisture with the surrounding ambient.[11–13,17] Thus, if the ambient is particularly humid, the tile absorbs part of this humidity, bringing it down to liveable conditions—never below 40% relative humidity (RH); inversely, when the ambient is very dry, the product releases part of the water retained inside it into the ambient, humidifying the air and creating comfortable conditions (RH below 70%). These two RH values are deemed to represent the ends of the most appropriate range of RH values for human beings to conduct their activities in a normal, comfortable way. Therefore, using this type of product as a coating for inner surfaces allows keeping ambient conditions in the bounded areas especially comfortable for those living or working there, smoothing the natural variations in ambient relative humidity, which occur, for instance, between day and night or as a result of changes in weather conditions (Fig. 6).

Further consequences of the particular workings of this product are the elimination of bad smells and of microorganisms that develop in areas with very high humidity. With regard to odours, the measure in which the tile absorbs ambient moisture also determines its capacity to absorb the volatile compounds that are responsible for unpleasant smells in the air and, hence, its air-purifying effect. These compounds remain fixed inside the porous structure of the piece, and do not return to the ambient when water desorption occurs. On the other hand, as ambient humidity is kept below 70% RH, drops of water do not condense; nor do microorganisms (mould, bacteria, etc.) form or grow, since the most suitable conditions for microorganism development involve high relative humidities and temperatures (Fig. 7). Thus, these product functions result in enhanced hygiene and habitability conditions inside the environments clad with these products (Fig. 8).

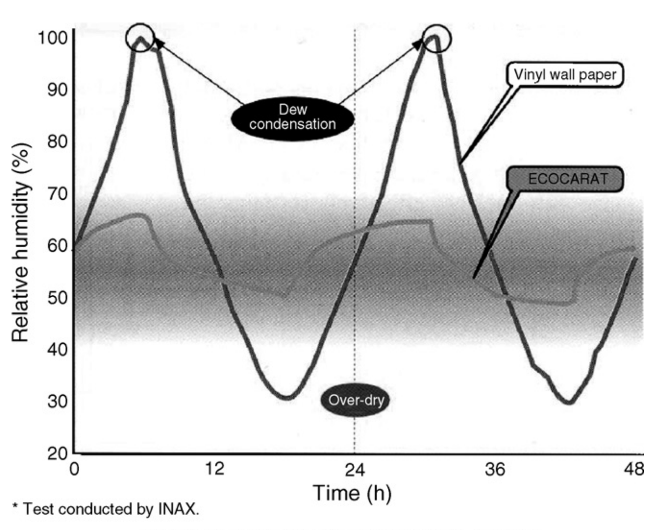


Fig. 6. Variation of ambient relative humidity with time.

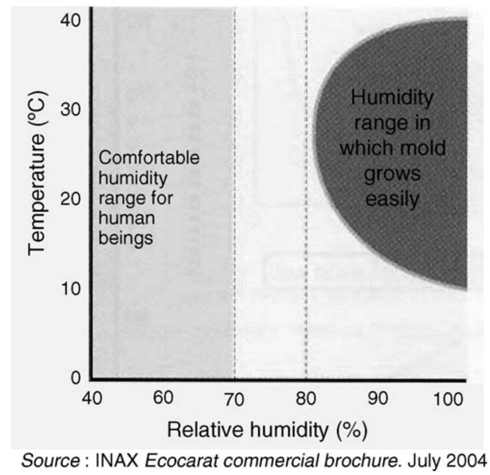


Fig. 7. Effect of ambient conditions on microorganism development and propagation.

These types of ceramic tiles display an extensive range of finishes and textures which are aesthetically comparable to those of conventional products. However, the fact that unglazed porous products are involved means that manufacturers' claims regarding product cleanability (a highly characteristic tile property) need to be appropriately verified, to ensure the product's suitability for its intended use.

4. Tiles fitted with functional elements

This field affords numerous possibilities, which increase daily as sensor, electronic and miniaturisation technologies, etc., continue making huge strides. What just a few years ago had seemed technically unattainable has today, in many cases, become a reality. Thus, a great variety of sensorial elements can now be fitted with relative ease in ceramic tiles, providing these tiles with novel, non-traditional functionalities.

Sensors can be fitted in pieces with different shapes – in the fair face or at the rear – and the electric signal they generate can be transmitted to multiple systems: lighting, acoustic or of other kinds. Moreover, this electric signal need not be transmitted through a physical medium (conventional wiring), but can be sent by telemetry (radio transmission), which further facilitates the installation of sensorised tiles.

However, the installation needs to take into account the fact that the electronic system required to process the signal detected by the sensor and convert it into an electric signal (possibly in addition to the radio emitter) is located behind the tiles. This requires leaving a small gap between the rear of the piece and the background, in which to lodge the processor. This gap (less than two centimetres wide) poses no particular problem, as similar systems are already commonplace in construction – for example in ventilated curtain walls or raised floors – for lodging multiple wiring installations.

Fig. 8. Influence of the type of coating on microorganism development.

If the sensorial element lies in the fair face, it needs to be suitably integrated in the surface finish in order to keep the desired aesthetic qualities. This can be done quite feasibly with the usual decorating systems, such as screen printing, rotogravure, etc., or by other more sophisticated systems (less widespread in the ceramic sector), such as physical vapour deposition (PVD). These systems allow depositing conductive layers that act as sensorial elements, while concurrently forming part of an appealing aesthetic design, for example by contributing metallized finishes, which are in great favour with consumers.

Thus, when contact is made with this conductive layer, an electric signal is generated that can turn on a source of sound, light, etc. This enables using such a system as a contact sensor, to turn on lights (switch), set off alarms or detect footsteps. In addition, since contact with water also produces this electric signal, these systems can be used as water leak detectors when the sensing surface is fitted, for example, at the bottom of skirtings or wainscoting (Fig. 9).

In an alternative type of installation, the sensing element becomes part of the rear surface of the piece, leaving the proper face unaffected. One such application is based on the use of pressure sensors. This allows using ceramic tiles as weight-measuring elements or, more simply, as footstep detectors, for safety purposes, statistics, etc. Another, even more attractive option involves using sensors that detect the proximity of objects or people through the tile, without contact with the tile surface; the resulting signal can then trigger alarms, turn on lights, open or close doors, etc. In both cases, the piece itself acts as a sensor, without any visible external signal.

These ways of installing sensing elements in ceramic tiles were presented by FRITTA S.L. (http://www.fritta.com) at the CEVISAMA 2004 trade fair in Valencia, where they were awarded an *Alfa de Oro* prize.

This same company, in co-operation with ISOFOTÓN (http://www.isofoton.com) and PAMESA CERAMICA, S.L. (http://www.pamesa.com) has developed and patented (WO 0115239) another extremely interesting application in which ceramic tiles are fitted with photovoltaic cells.[9] Here, conventional photovoltaic cells are mounted on porcelain tile bodies by a process based on the application of transparent protective coatings, which provide the pieces with the necessary properties to enable them to withstand outdoor conditions: cell adhesion, cell thermal insulation from the external environment and surface mechanical strength. Thus, ceramic tiles become electrical energy generators, using sun energy as a renewable power source. The system enables assembling solar panels in architectural structures, for example using these pieces as roof coverings, or combining the power-generating function with use, for instance, as a sound barrier. This twofold function is embodied, for instance, in an installation along a motorway in Germany, which has been operating for over 2 years (Fig. 10).

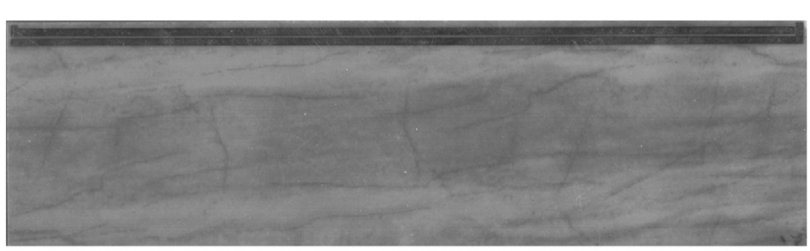


Fig. 9. Ceramic skirting with fair-face sensing surface.

Fig. 10. Panel of porcelain tiles fitted with photovoltaic cells.

Finally, a further type of functionality (different from the foregoing) deserves to be noted, which provides more agreeable environments: in this case, ceramic tiles are fitted with elements that dispense volatile aromatic substances, which diffuse into the atmosphere, providing a pleasant smell. These ceramic items therefore act as air fresheners and odour neutralisers, or fragrance dispensers.

These products are ceramic trims, behind whose curved surface lies a device containing the air freshener. This air freshener reaches the surface by means of a small tube, open to the outside, through which the product is progressively dispensed. A second tube in the trim has the opposite function, namely to replenish the air freshener. The trim finish integrates the entry and exit openings of these tubes in an attractive design (Fig. 11).

This item was presented at the CEVISAMA 2005 trade fair in Valencia, where it was awarded First Prize in the International Industrial Design and Technological Innovation Competition.

Fig. 11. Listel fitted with an air freshener.

5. Conclusions

Summing up, in this paper we have highlighted a few of the multiple possibilities that are currently opening up in ceramic tile uses, based on new, hitherto unexplored, tile functionalities. We have briefly described a few functionalities that are now already industrial realities, but a great many more can be expected, if this line is further pursued. This will require close collaboration between the different actors involved in generating and using these new applications, ranging from ceramic tile manufacturers to specifications writers, architects and interior designers, in order to exploit fully all the potentialities afforded by these products.

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