The Spanish and Italian ceramic tile manufacturing sectors (which also includes raw material suppliers and producers of bodies, glazes, frits, engobes and pigments) are facing a most singular moment in their history.

First of all, they need to overcome the economic downturn that started in 2008 before going on to deal with the fierce competition from other countries emerging as competitive producers in the post-crisis scenario.

Interior of Star City Casino, Sydney. Lightweight, advanced ceramic products produced by Laminam and installed by Living Tiles are just one of many radical new products that will determine the industry’s future. Laminam recently appointed new Australian distributors which include CDK Stone and Living Tiles.
Nowadays, the sector has a more or less homogenous character in which the different companies tend to produce very similar materials and therefore compete for the same market. This paper proposes two alternative but compatible road maps that provide a possible future strategy to diversify the sector’s supply offer by planning its R&D+i to: i) achieve significant production cost savings for standard ceramic products, and ii) to develop new specialised ceramic materials that meet the specific cultural and practical needs of each particular market environment. In the short term, the ideal strategy would be to develop the first alternative in order to produce ceramic bodies at significantly lower firing temperatures than at present, the immediate effect of which would be to reduce glaze thickness and the amount and size of pigment particles, thereby opening the way to mass usage of thin-film decorating techniques (such as ink jets) and even laser techniques. In the medium and long term, the second alternative needs to be followed, to increase the overall added value of ceramic tiles, which depends on the skills and ingenuity of researchers and technicians alike to come up with a wide-ranging diversity of ceramic products.

Introduction

When one analyses the relative significance of the role played by classic ceramic (CC) materials (traditional ceramics: floor and wall tiles, bricks, refractory materials, tableware and ceramic bathroom fittings, etc. that basically attend primary human needs, especially home-building needs) and advanced ceramic (AC) materials (or technical ceramics, which apparently mainly refers to materials covering secondary human needs, e.g. in telecommunications), the world of ceramics seems to be “two-headed”, “twin-moded” and “asymmetrical”. It is twin-headed in the sense that researchers tend to choose to devote their professional skills to either CC or AC. It is “twin-moded” in the sense that its manufacturing companies, and even producer countries, also tend to opt for either CC or AC. Nevertheless, the sector is also highly asymmetrical, in that the number of publications and concerted research devoted to CC is much lower than for AC, although turnover in economic terms is much higher worldwide for CC than for AC. Figure 1 shows turnover by sub-sectors throughout the world according to a report by the Cookson Company published in 2006, where AC can be seen to account for only 19 per cent.

In Europe, a report by Ecorys, commissioned by the European Community, to study the competitiveness of the European ceramics sector also revealed this same asymmetric character. Turnover in the sector in 2006 reached 28,000 million euros, split as follows: floor and wall tiles 36 per cent, bricks and roof tiles 24 per cent, refractory materials 12 per cent, technical ceramics 10 per cent, bathroom fittings 8 per cent, and ceramic tableware 6 per cent (N.B. –74 per cent is based on triaxial ceramics!!). That same year, the sector had 221,000 employees, of which – 83 per cent were dedicated to CC. France, Germany, Holland and the UK are the main producers of AC, while Spain and Italy head the list of CC producer countries. This asymmetry arises once again.

Current ceramics

Ceramic tile manufacturers are already familiar with the results of the in-depth innovation process that took place in the 1980s, when dry route body processing was replaced with wet route body processing using clay spray-drying technology. As a result of this change, a “ceramic tile revolution” took place, which completely changed the type of tiles manufactured prior to that date (see figure 2). The result was that traditional double-fired products almost disappeared to be replaced by porous single fired tiles, while the use of single-fired flooring (stoneware) also expanded significantly. Nowadays, red body tile output accounts for between 70 and 80 per cent of the total, the rest being white body production (in which imported raw materials are used in most cases - between 60 and 85 per cent of the total formulation), while the production of porcelain stoneware is a minority (around 6.5 per cent). In other words, the current situation is still the result of the inheritance of the aforementioned change in technology, based mainly on the use of local raw materials. It should be mentioned that remarkable efforts have been made to use national raw materials in white body formulations for stoneware and porcelain tile6 8, where their incorporation into white bodies has been enhanced by purifying local clay using magnetic separation.

However, the current trend shows that the stoneware/porcelain tile or white body/red body tandems are tending to disappear as synonyms of differing quality, and numerous bodies have arisen with ‘hybrid’ formulations (including classic compositions, i.e. mixtures of red clays for stoneware and white clay-kaolin with feldspars
for porcelain, in some cases by adding low proportions of carbonates which have led to greyish and reddish hues with open porosity rates of less than 0.5 per cent and mechanical properties comparable to white porcelain levels.

However, traditional red body compositions (mixtures of flux and plastic clays with other compacting and refractory materials which, when fired at 1140°C, provide an open porosity of 3-4 per cent and ~ 7 per cent of linear shrinkage) is still the dominant material and therefore the one on which future research efforts should be based.

Ceramic decoration is also undergoing a significant transition from traditional (albeit modified) screen printing techniques using pigments with particle sizes of around 5 μm to other techniques based on ink technologies and printers with different kinds of heads, for which the ideal particle size is under 1 μm. This requires improved grinding of the material on its exit from the kiln (once specific grinding processes have been researched) and more stable (or less soluble) pigments at firing temperatures, a target which entails the greatest difficulty, especially to decorate porcelain tiles (Tc ~ 1170°C). Alternative manufacturing procedures have also been researched for pigments that would produce the required grain size directly; such as the ‘sol-gel’ technique, and for inks containing dissolved chromophores. Another directly related case is that of metallic glazes with significantly different decorating capabilities.

### Competitive Ceramics

Since 1982, the sector has carried out widespread investment in plant and machinery, materials and human resources, in the same way as its counterparts in competing European countries or in other parts of the world since the 1990s. These new producer countries have benefited from inherent advantages (whether in the use of local raw materials, labour costs or variable restrictions in environmental matters), although they use identical production technologies, mainly of European origin. Therefore a change is required which will allow currently available technologies and materials to be used to produce ceramic tiles at a significantly lower overall cost than at present...

![Figure 2. Diagram of the technology change from dry route to wet route production in 1982 and the resulting upgrading of the type of ceramic tile production in Spain.](image)

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![Figure 3. Diagram of approximate cost split for different types of ceramic tile, where, apart from employment, the greatest costs relate to raw materials, glazes and colours, which indicates where cost saving strategies should be focused.](image)
more advanced (and relatively more costly) materials can be employed, which would then extend the number of decorating techniques available for use, such as thin-film printing or laser-induced crystallisation techniques\(^8\) and other such technologies\(^9\) – see diagram summary in figure 4. Consequently, as maximum firing temperature \(T_{\text{max}}\) comes down, the overall competitive and cost-saving benefits would increase in the same direction, like a positive feedback process. Nevertheless, from the technical point of view, reducing \(T_{\text{max}}\) in red bodies is not the same as reducing it in white bodies, as sintering in red bodies is mainly linked to surface phenomena affecting compacted particles, while in the latter case, sintering is a liquid stage that occurs when feldspars and other fluxes melt. Therefore, re-formulation in one case may be very different from the other. On the other hand, \(T_{\text{max}}\) in wall tiles could be reduced by using carbonates with lower decomposition temperatures. Obviously, under no circumstances should increased fusibility be achieved in bodies by sacrificing dimensional stability or firing heat ranges. Thus, low \(T_{\text{max}}\) bodies depend on the development of advanced fluxes and high-density spray powders, for which the role of particle surface stress needs to be studied. In conclusion, to be competitive, ceramic products need to blend savings on materials (many of which are now scarce) with reduced fuel and energy costs, thereby reducing emissions of pollutant gases – all of these being ideas compatible with the concept of “sustainable development”.

smart ceramics

Recent history shows that any planning carried out in the industrial world needs to take certain issues into account, such as energy (linked to raw materials from well-defined geographical locations) and super-population (therefore, ‘megamarkets’ especially in Asia), and consequently to consider them from the viewpoint of sustainable development. Companies manufacturing GC cannot suddenly switch to producing advanced ceramics and compete in a market that is alien to them and has very different characteristics\(^11\). They can, however, echo the social demands that such materials cover in order to gradually incorporate them into their products. In short, it is a question of transferring technological innovation to the ‘smart home’ – see diagram in figure 6 – where a house can be valued in terms of decorating techniques available for use, such as energy saving and health & safety, personal hygiene and quality of air. With regard to the first matter, a historical look at the automobile industry shows that investment in health and safety has always had a social and market component which guarantees success. There exist numerous environments in which health and safety can be instilled into ceramic tiling, for example, in centres using ionising radiation such as hospitals, radiotherapy centres and research institutes. In these cases, radiation-proof wall plating could be supplied using ceramics with high density crystalline phases with heavy, radiation-passivating chemicals.

The questions of personal hygiene and air quality relate to the photocatalytic effect\(^14\) of bactericide and air cleaning products. The first question stems from biocide materials that initially used Ag particles and later Ag\(_2\)TiO\(_4\) particles and is already being explored by several companies. The second question is receiving growing attention, as in many cases the use of air conditioning systems is considered to be an unhealthy solution. Figure 5 illustrates a diagram of the photocatalytic effect on TiO\(_2\) with an anatase structure. Given that this material is activated by ultraviolet (UV) radiation, alternatives are being sought for its use indoors where the effect is achieved by radiation within the visible energy range. Additionally, modifying surfaces using laser technology to increase the active surface area would be a highly positive step towards generating nano-roughness\(^16\) and therefore a greater active surface, which is a technique of special interest when the thickness to be modified is sufficiently small.

ceramics for healthcare

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ceramics for energy

It is important to highlight that in Europe, it is estimated that housing overall uses ~40 per cent of all consumed energy, which in turn accounts for ~25 per cent of CO\(_2\) emissions. Therefore, questions relating to energy production and energy saving in domestic homes should be treated separately. From the point of view of production, the ceramic world is leading a change in attitude. The sun is no longer an item of concern whose energy blanches and damages the ceramic beauty of outside façades and has become an ally to home maintenance, i.e. a means of producing energy, whether photovoltaic, thermal or both. Theoretically, the solution is ideal for a material whose function is to cover large surface areas, as it represents unlimited, clean energy, free of transport costs, with no geopolitical dependence and of special interest in geographical regions with many hours of sunlight per year (for example, in areas such as ours). And of course in Australia!
Early generation photovoltaic energy is mainly based on the production of monocrystal or polycrystal-line silicon chips in cells to form panels which, in turn, are fitted as totally foreign appendices on buildings. In this case, no ceramic or glass substrate is required for these devices to work. However, second generation photovoltaic energy calls for savings in raw materials (semiconductors), which at present means sacrificing energy efficiency, and uses thin layers of different semiconductors in tandem (for selective absorption of different wavelengths) on glass, ceramic or even plastic substrates, giving rise to a technology now known as BiPV (built-in photovoltaics)\textsuperscript{14}, i.e. these devices form an integral part of the building. In this generation, the substrate and the thin multilayer device are not two independent entities but rather building efficiency depends on the degree to which technically they can be coupled together, so their glass and/or ceramic character is essential. Although at present glass substrate panels have been much more widely implemented than ceramic-based panels, the latter possibly afford greater installation opportunities. Consequently, certain confid- dentiality exists regarding the nature of these ceramic bases when results are presented by specialist companies from the sector\textsuperscript{17,18}, although data is available about devices with mullite\textsuperscript{19} and zircon\textsuperscript{20} substrates, among others. Finally, it should be mentioned that a third generation is currently being de- veloped, although still at the research level, in which ceramic and glass ma- terials may become an integral part of all the components in these devices\textsuperscript{21}. With regard to ceramics for energy-saving, an analysis of heat gains and losses in buildings (efficiency) needs to be made from a climatic point of view, given that this affects potential markets with very different require- ments. Therefore, a first distinction should be made between two contrasting situations: “daylight architecture” for cold climates and “sunlight architecture” for warm climates. In the former case, emphasis is on the use of ceramic materials to absorb sol- lar heat energy (during the day), which is then slowly released during the night, while in the latter case, these materials should not accumulate heat but rather enable nighttime ventilation of the building. In this sense, studies have been carried out on the near infra- red reflectance of different inorganic pigments\textsuperscript{22} to obtain ceramics that help to prevent indoor temperatures from rising, thereby providing energy savings by reducing the time that air condition- ing units need to be used.

Ceramics for comfort

Given that in many industrialised countries, we spend a large part of our time indoors (up to 90 per cent in the so-called first world), it is easy to un- derstand the importance of comfort, which in many cases is associated with productivity. This concept should be interpreted in terms of:

i) Noise and vibrations: the impor- tance and need for insulation and especially noise insulation and buff- ering is not limited to large-scale sports installations and swimming pools. These questions are of great importance in many instances in buildings that have already been erected, especially for economic solutions that do not entail large losses of space.

ii) Humidity: humidity con- trol by means of ceramic wall coverings is an innovative idea which is already being exploited by manufactur- ing companies and consists of materials made of special bodies which absorb or emit water depending on the ambient moisture level.

iii) Installation control: this is a field that has already been initiated by certain Spanish ceramic companies\textsuperscript{23} and is based on the concept of “home automation”, which consists of integrating information technologies and telecommu- nications in the home. In this regard, automatic control systems have been developed for all the instal- lations in a house, including tiles (by means of sensors and WiFi devices) which have the following advantages: greater strength than current (plastic) devices, easier to clean, possibility of incorporating Braille codes, and versatility.

Cultural diversity: partially or totally subjective factors, pre- ferred designs and/or particular beliefs: One particular aspect such as colour does not have the same meaning or influence in the East as in the Western world. Although in Western Europe, it is possible that a sufficient number of houses already exist to cover the needs of the next generation, there are nu- merous emerging markets where individual wooden buildings are going to be replaced or ex- tended by constructions where ceramica and glass will play a more prominent role. It should be noted in this respect that comfort is linked to daily issues -the natu- ral stage for ceramics – which fortunately do not have the same relevance nor refer to the same daily routines in all cultures.

Conclusions

Nowadays, the Spanish ceramic tile manufactur- ing sector is highly homogenous with regard to the products it markets, the prominent features of which are surface deco- ration (glazes and pig- ments) and the colour of the firing body (the substrate), when tiles with identical mechani- cal properties are com- pared. From a technical
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REFERENCES