COMPARATIVE STUDY OF POLISHED PORCELAIN TILE PROPERTIES

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ABSTRACT

The present paper sets out a comparative study of the properties of a wide sampling of polished porcelain tiles produced by various companies from different countries.

The microstructure of these materials has been evaluated using X-ray diffraction to identifying their crystalline components. Pore-size distribution was determined at the polished surface. The aesthetic properties (gloss and stain resistance) of these surfaces were also studied after polishing the samples in laboratory conditions (eliminating imperfections attributable to industrial polishing). With regard to mechanical properties, bending strength, toughness and scratch resistance were determined. Finally, wear tests were run on the tiles and grinding tools using a tribometer recently developed for simulating the industrial polishing operation.

In attempting to establish relations between these properties, it was confirmed that tile gloss and stain resistance were exclusively dependent on surface porosity. It was furthermore verified that crystalline phase content (principally quartz, but also mullite) largely defined tile mechanical behaviour, evaluated in terms of mechanical strength and toughness. Finally, it has been possible to satisfactorily relate tile wear rate in the tribometer to toughness, i.e., to the crystalline phases contained in the tile.

1. INTRODUCTION

The technical performance and aesthetic features of porcelain tile have been widely described in the literature[1]. Porcelain tile may be glazed or unglazed. The porcelain tile body is characterised by low porosity (water absorption below 0.5%), which provides high mechanical strength and frost resistance. The porcelain tile surface is often subjected to grinding and polishing, which hardly affects tile mechanical properties, to enhance its aesthetic qualities by producing high-gloss surfaces. It is precisely this last product which is most valued in the market, as a result of the excellent combination of technical performance and aesthetic characteristics.

Porcelain tile production of the main porcelain tile manufacturing countries has witnessed spectacular growth in recent years. In particular, the world's top two porcelain tile producers, China and Italy, have more than doubled their production in just 5 years, making porcelain tile account for over 50% of total ceramic tile production in both countries. It should be noted however, that Chinese production focuses more on polished porcelain tile, whereas Italian production is more directed towards unpolished glazed porcelain tile. Spain, the world's third porcelain tile producer at quite some distance behind the two foregoing countries, maintains slow but steady growth. At present, porcelain tile accounts for 6% of total Spanish ceramic tile production.

Although the increase in porcelain tile production has been very important, relatively few studies have appeared on this type of product. Most of these papers have dealt with manufacturing technology or the machinery involved in the different process stages. Few papers are thus available on porcelain tile properties, and even fewer that try to explore the complex relations that exist between fired product microstructure and properties. This microstructural dependence is particularly noteworthy in the polished product, since grinding exposes part of the closed porosity at the tile surface, causing tile porous microstructure to affect not only the properties of the entire piece, but also surface properties, such as gloss and stain resistance[2]. In view of the foregoing, the present study has been undertaken to try and relate polished porcelain tile microstructure to certain tile mechanical properties (mechanical strength and scratch resistance) and surface properties (gloss and stain resistance). The polishability of the material has also been evaluated, using a novel tribological technique, attempting to relate tile behaviour to its mechanical properties. The study was conducted using industrial porcelain tiles made by representative companies from different countries.

2. EXPERIMENTAL

2.1. MATERIALS

The study was conducted using nine industrial samples of porcelain tile manufactured by Spanish, Portuguese, Italian and Chinese companies. Figure 1 shows a photograph of each type of tile.

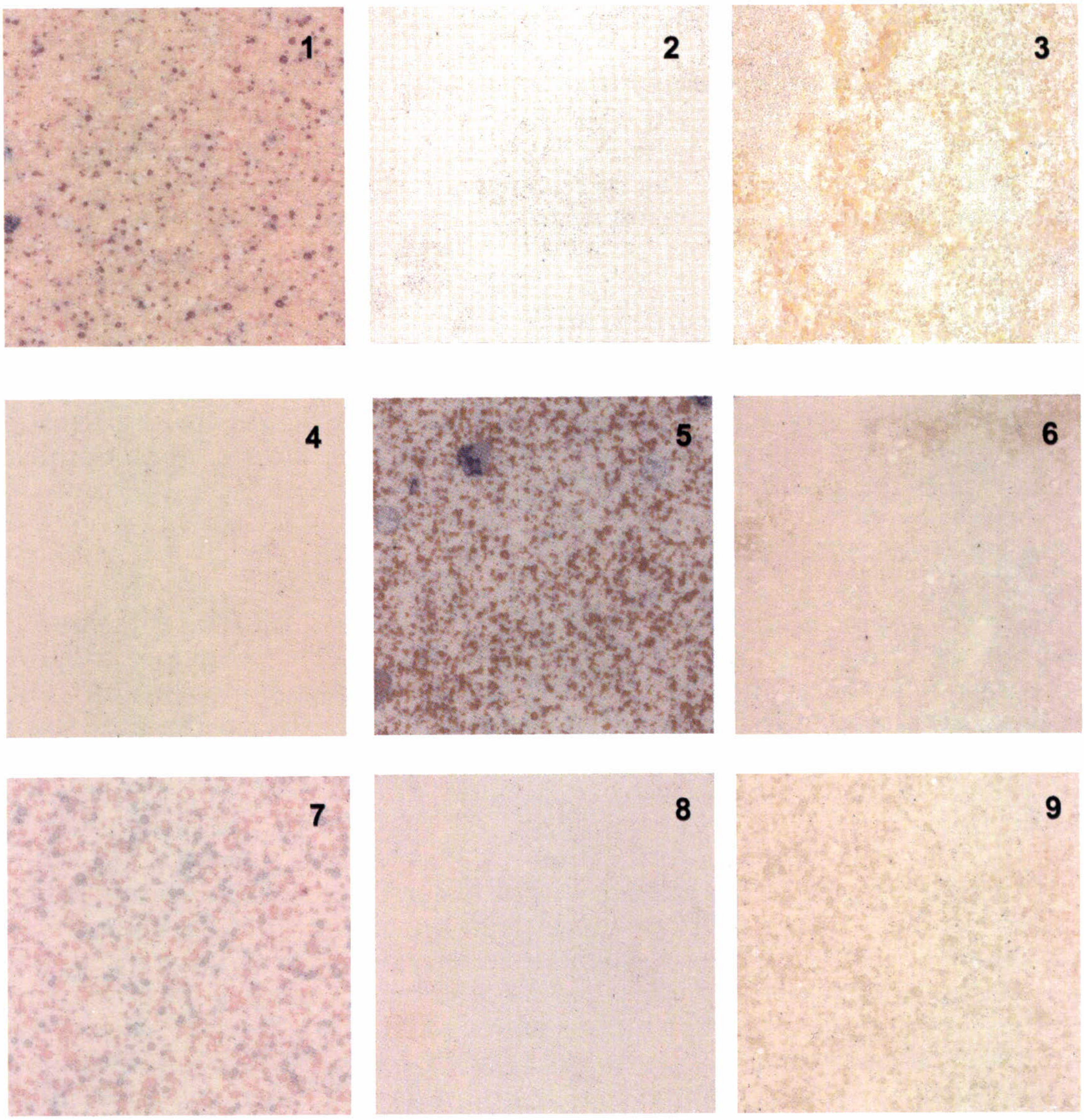

Figure 1. Photograph of the nine tested samples of industrial porcelain tile

The samples, which have been randomly numbered 1 to 9, can be described as follows:

Sample 1: "Salt and pepper". Pink base with beige and dark grey mix.
Sample 2: Plain white base
Sample 3: Flecked with large white and beige areas
Sample 4: Plain beige base
Sample 5: "Salt and pepper". Mix of light and dark beige tones. Presence of dark grey granules of larger diameter.
Sample 6: Flecked. Light beige base with white areas and dark beige surface patches.
Sample 7: "Salt and pepper". Mix of beige, pink and light grey tones.
Sample 8: Plain light beige base
Sample 9: "Salt and pepper". Light beige and beige.

Because some samples had a natural (as-fired) surface, whereas others had been polished, for the surface tests test specimens were used that were polished beforehand in the laboratory, according to a standard procedure described elsewhere[3].

2.2. EXPERIMENTAL PROCEDURE

2.2.1. *Identification of crystalline structures*

The crystalline structures were identified by X-ray diffraction of the powdered sample with a diffractometer. The percentage of quartz, mullite and zircon was quantified by the method with the internal standard. Anorthite was determined using the RIR method.

2.2.2. *Evaluation of microstructure*

The surface of the samples, polished in the laboratory to 1 μm grain size diamond, was observed with the aid of an optical microscope in the bright field. Connecting an image analyser enabled determining the surface area occupied by pores, as well as the size distribution of these pores.

2.2.3. *Mechanical properties*

Mechanical strength was determined on a universal testing machine by a three-point bending test. This procedure was also used to evaluate toughness. For this, a flat notch with an approximate thickness equivalent to 40% of the thickness of the piece was made with a diamond disk. The mechanical strength value obtained with the notched test specimens then enabled calculating the toughness of the material, according to a widely used procedure described in the literature[4].

The scratch test was conducted with a tester fitted with a diamond-coated conical indenter, with a 120° opening and spherical tip of 200 μm radius (Rockwell C). Several scratches were made under constant loading on the surface of the samples, progressively increasing the load by 1 N steps. Topographic maps were then made with a roughness meter of the resulting tracks. These topographies show the appearance, at a given load, of a groove on the test specimen surface, which becomes wider and deeper as load increases up to a given value, at which the groove is no longer clean and the material begins to fracture. The value of this load is recorded as Q_D[5].

2.2.4. *Aesthetic properties*

Gloss was measured with a reflectometer. Ten measurements were run for each tile at an angle of incidence of 60°. The arithmetic mean and standard deviation of the resulting values were then calculated.

The stain test was carried out on cylindrical test specimens cut from the received samples whose surface had previously been polished. The chromatic co-ordinates were measured with a colorimeter using a CIE C standard illuminant and CIE 2° standard observer. The chromatic co-ordinates of the clean test specimens were measured first (L_0^*, a_0^* and b_0^*). Their surface was then painted with an indelible ink labeller and allowed to dry for some minutes, after which the ink rests were wiped off with a water-dampened cloth. After drying the surface with a dry cloth, the chromatic co-ordinates were measured again and parameter ΔE^*, related to colour change, was calculated[6]. The specimens were then subjected to periodic cleaning stages by means of a device that pressed a scouring pad soaked in ethanol, with a set load, rotating at a constant speed, onto the surface. After each cleaning stage, the chromatic co-ordinates of the surface were measured again, then calculating parameter ΔE^*. This process was repeated until test specimen colour remained constant.

2.2.5. *Wear tests*

In order to evaluate the polishability of the studied materials, wear tests were carried out in a recently designed laboratory tribometer that simulates the industrial polishing process, developed within the framework of a European project by the Institute for Manufacturing of the University of Cambridge. The fine-tuning and validation of the tribometer are set out with elsewhere, in another paper presented at this same congress[7]. The configuration of the test consists of a single abrasive pin (10 mm high and 10 mm diameter) pressed under constant load against the tile (100x100 mm), with its cylinder axis horizontal and parallel to the surface of the tile and rotating on a vertical axis. The tile rotates in the opposite direction to that of the abrasive pin. Adjusting tribometer operating conditions then enables simulating the relative movement well that occurs in industry between the abrasive block and the ceramic tile.

The abrasive pin, of the same composition as the grinding tools (fickerts) used in industrial polishing, consisted of a matrix of magnesium cement and SiC abrasive grains. Since it was only intended to determine the porcelain tile wear rate, a very effective coarse abrasive grit (# 46) for material removal was used. Test conditions, which were kept constant in all the experiments, were as follows:

- Charge per unit of contact: 1.7 N/mm
- Tile rotating speed: 300 rpm
- Abrasive pin rotating speed: 150 rpm
- Polishing time: 60 s

The test allows determining the volume loss of the abrasive pin and the abraded workpiece as a function of time. The experimental data are used to calculate the specific wear rate (m^3/Nm) of both materials, and their ratio (m^3 abraded tile/m^3 abraded pin), which is related to polishing process efficiency.

3. RESULTS AND DISCUSSION

3.1. MICROSTRUCTURAL CHARACTERISTICS

Table I1 sets out the crystalline phases present in the pieces, with their proportions. These crystalline phases are the result of the presence of refractory minerals in the raw materials used, which have not decomposed or melted, or of crystallisation and devitrification processes that occur during the firing stage. The table shows that the major crystalline species is quartz (SiO_2) followed by mullite ($2SiO_2{\cdot}3Al_2O_3$), zircon ($ZrSiO_4$) and albite ($NaAlSi_3O_8$). The presence of a small amount of anorthite ($CaAl_2Si_2O_8$) was also observed in one of the samples.

Quartz and mullite are respectively found in all the test pieces in percentages of the order of 15% and 5%. To be noted is the low quartz content of sample 3. Quartz is a mineral that is usually present in the raw materials used in these compositions (in siliceous or feldspathic sand, but also in clays and even in feldspars). Its high melting temperature, as well as the high viscosity that it contributes to the liquid phase in which it integrates prevents its total dissolution during the firing stage. In contrast, mullite is a compound that crystallises at temperatures exceeding 980°C, mainly from the clay minerals of a kaolinitic structure[8]. The presence of this crystalline species is also in accordance with the characteristics of the clays used in the manufacture of porcelain tile (with clay minerals of a kaolinitic-illitic type).

Sample	Quartz	Mullite	Zircon	Albite	Anorthite
1	18	6	-	5	-
2	13	6	7	-	-
3	7	5	4	-	6
4	18	8	-	-	-
5	17	7	2	-	-
6	15	4	3	5	-
7	14	4	2	-	-
8	20	7	-	-	-
9	18	3	1	7	-

Table 1. Crystalline phases contained in the tiles (% by weight).

Zircon and albite only appear in some of the tiles. Zircon is used as an opacifier and can be contributed as an ingredient or crystallise during heat treatment, which in the latter case would mean the incorporation of fritted materials into the starting composition. However, judging by its particle size (>3μm) evaluated by scanning electron microscopy (SEM), it seems rather unlikely that it devitrified during firing. On the other hand, albite is a residual crystalline species, like quartz, which comes from the raw materials in the composition. Finally, the presence of anorthite, albeit in a small quantity in one of the samples, must due to the inclusion of crystalline raw materials or glassy contributors of CaO in the starting composition. This compound contributes to tile opacification together with zircon.

Table 2 details the percentage area occupied by pores and the pore diameters corresponding to 16, 50 and 84% of porosity, determined from the pore-size distribution curves. Although all the samples are observed to display values of the same order of magnitude for these characteristics, the differences among them are important, as they will affect tile end properties, as shown further below. In general, pore size increases as porosity rises. This highlights the difficulty of eliminating large pores during firing[9]. Sample 4 is noteworthy for exhibiting the lowest porosity and smallest pores. Sample 8 lies at the opposite end of the spectrum, exhibiting quite a high porosity with larger pores than the rest, mainly because of its high quartz content (20%). Sample 6 also has large pores, although in this case they are not associated with an excessive quantity of quartz in the fired piece.

The photographs obtained by optical microscopy (Figure 2) show the porosity of the polished tile surface and pore morphology. While samples 1, 7 and 9 display a porous structure made up of very irregularly shaped pores, which in certain cases are interconnected, the photographs corresponding to samples 6 and 8 depict porosity consisting of large round pores. These differences are related to the varying degree of firing of the samples. Thus, the presence of numerous small pores and the irregular shape of the larger ones indicate underfiring, whereas the presence of large round pores without any small pores is the result of overfiring[9].

Sample	Porosity (%)	d_{16} (μm)	d_{50} (μm)	d_{84} (μm)
1	7.1	5.4	12.1	26.9
2	8.2	5.0	10.6	24.5
3	8.9	4.9	10.2	23.5
4	4.9	4.5	8.3	19.6
5	8.0	5.6	11.8	26.4
6	6.9	6.9	16	39.4
7	5.9	5.0	10.5	31.0
8	9.0	8.4	19.4	38.5
9	7.6	6.3	15.2	33.8

Table 2. Surface porosity and pore size of the nine studied samples

When it was attempted to correlate the parameters that define tile porous structure (porosity, d_{16}, d_{50} and d_{84}) with the phases present in these tiles, no satisfactory trend could be identified. This is because fired product microstructure depends not only on composition, but also on processing (particle and granule size distribution, pressing compactness, firing cycle, etc.). This indicates the great importance of tile processing on final fired microstructure, an aspect that can not be addressed in the present study.

As an example, Figure 3 shows the SEM images corresponding to samples 3 and 8, with very different quartz contents, namely of 7 and 20% respectively. Whereas sample 3 evidences large dark grey particles (30 μm) with well-defined boundaries (quartz), the quartz particles in sample 8 display diffuse boundaries and more are integrated in the glassy matrix. The images of this sample show no significant changes of colour, which indicates that the glassy phase is more homogeneous. These differences can be related to particle size distribution of the starting compositions. Thus, sample 3 with a smaller quartz content should have low porosity. However, the composition has apparently undergone little milling, leading to porosity quite similar to that of sample 8 with a high quartz content.

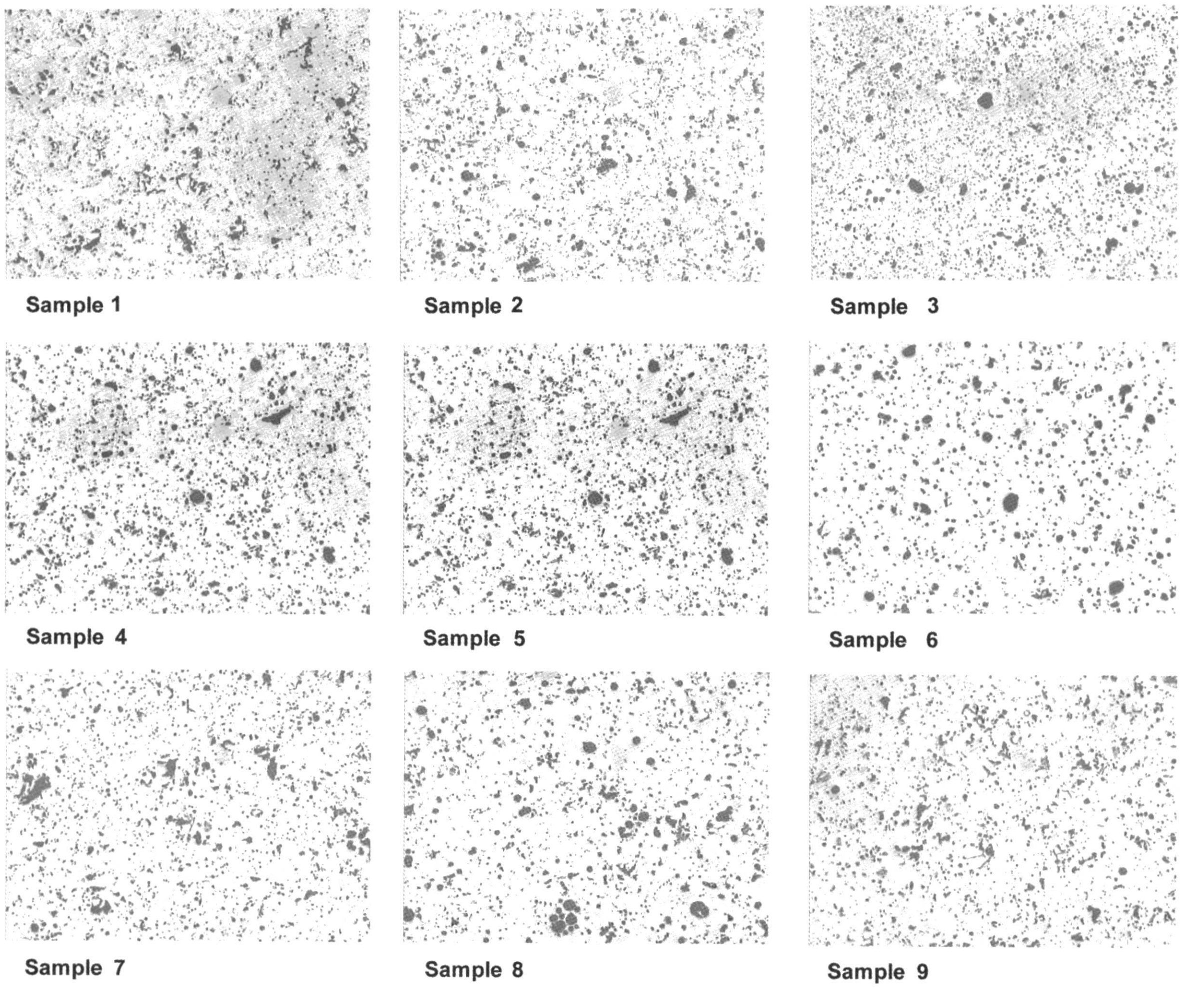

Figure 2. Photographs of the polished surface of the nine test samples

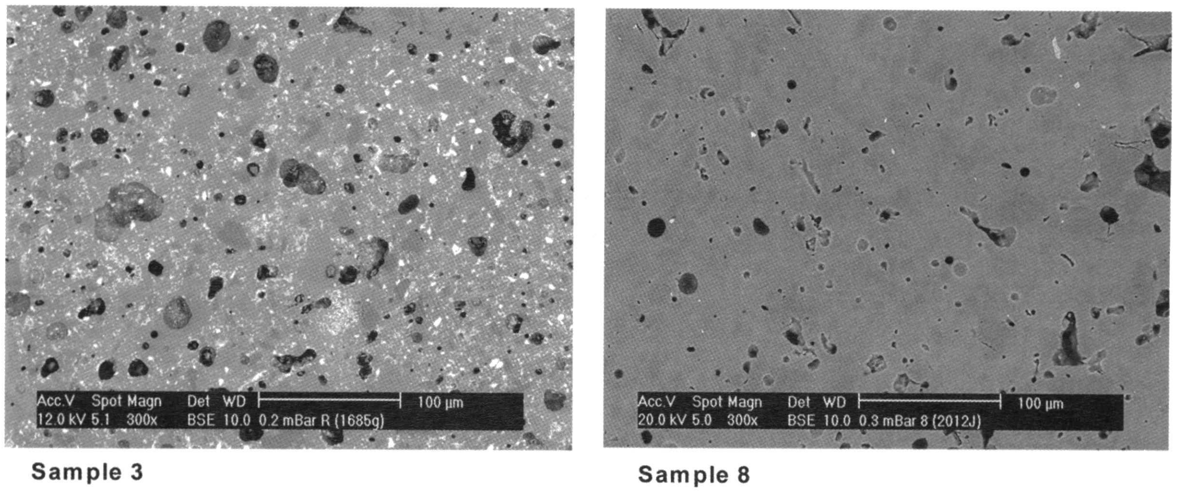

Figure 3. Micrographs of the polished surface of samples 3 and 8

3.2. MECHANICAL PROPERTIES

Table 3 details the values obtained for the mechanical properties of the samples: mechanical strength (RM), toughness (K_{Ic}), and scratch resistance evaluated by parameter Q_D.

Sample	RM (GPa)	K_{Ic} (MPa·m$^{1/2}$)	Q_D (N)
1	74±12	1.63±0.10	30±1
2	74±17	1.59±0.20	29±1
3	57±12	1.50±0.05	28±1
4	77±15	1.73±0.04	34±1
5	75±14	1.79±0.09	35±1
6	42±7	1.45±0.10	29±1
7	71±14	1.67±0.08	32±1
8	93±34	1.67±0.11	34±1
9	71±13	1.71±0.10	32±1

Table 3. Mechanical properties (mechanical strength, toughness and parameter Q_D) of the nine test samples.

In order to study the influence of the mineralogical composition of the fired tiles on their mechanical properties, Figures 4 and 5 respectively plot mechanical strength and toughness versus quartz content, the major crystalline species in all the samples. Figure 4 shows that except for sample 6 (15% quartz content), the rest of the studied materials exhibits good correlation between mechanical strength and quartz content in the fired product. Quartz, originating in the starting raw materials, partly dissolves in the liquid phase that develops during the sintering process, though most of the quartz remains undissolved as a result of high melt viscosity. The presence of quartz particles dispersed in the glassy matrix strengthens the material (increases toughness) as a whole, raising mechanical strength. On the other hand, the linear relation exhibited between quartz content and mechanical strength in the studied range of quartz contents indicates that the saturation value of the strengthening stage, predicted by certain researchers in other materials, has not been reached[10].

Various studies have already dealt with the role of quartz as a strengthener, both for porcelain[10],[11] and porcelain tile[12]. The literature indicates that quartz essentially reinforces the structure of the porcelain tile glassy matrix by two mechanisms: crack deviation and microcrack formation. Plotting toughness versus quartz content shows good linear correlation, with the foreseeable scatter for materials of such differing nature, which confirms the strengthening effect of quartz. As was the case with mechanical strength, sample 6 departs from this behaviour. The reason for this deviation is probably due to two factors. The first stems from the microstructural differences mentioned above, which this sample displays in respect of the rest, since its microstructure is characteristic of a state of overfiring with abundant glassy phase. The second factor is the nature of the fired material itself, which is made up of phases presumably originating from mixing powders of different composition and particle size (Figure 1).

Results similar to the foregoing were observed when mechanical strength and toughness were plotted against the sum of quartz and mullite content. These results also confirm the reinforcing role of mullite in porcelain tile, as certain researchers have demonstrated[8]. However the mullite contribution is smaller than that of quartz, because it is generally found in small quantities, as the fast firing cycles by which porcelain tile is fabricated do not favour mullite formation.

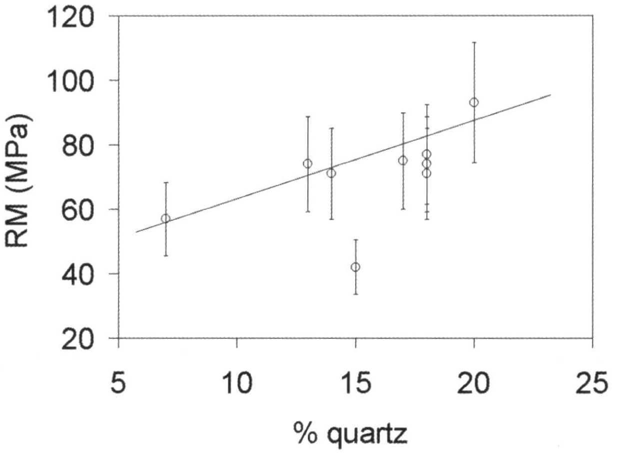

Figure 4. Influence of quartz content on mechanical strength

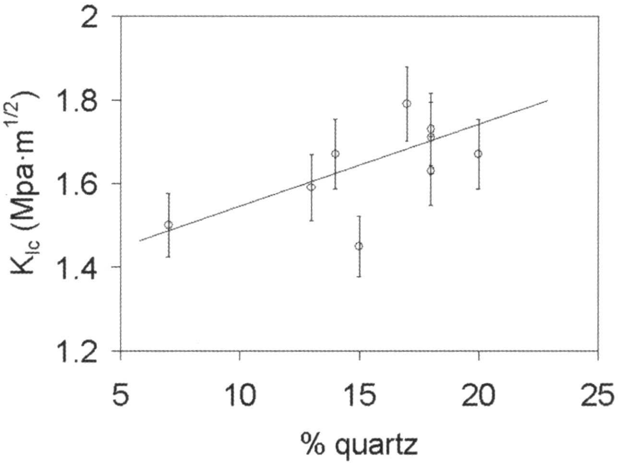

Figure 5. Influence of quartz content on toughness

On the other hand, when it was attempted to relate both mechanical properties to the porosity of the samples, no clear trend could be observed. This indicates that although fired tile porosity ranged from approximately 5 to 9%, the strengthening effect of the crystalline materials present (quartz and mullite) prevails, as opposed to structural weakening associated with the presence of porosity in the fired pieces.

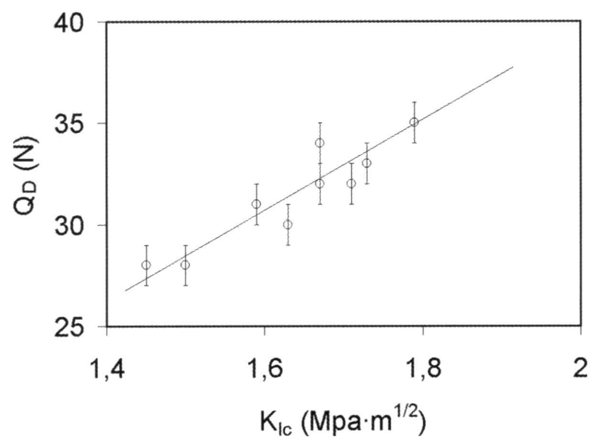

Figure 6. Relation between toughness and scratch parameter Q_D

Finally, Figure 6 plots parameter Q_D (load at which flaking first appears in the scratch test) versus toughness. The figure shows very good linear correlation between these two properties. This is reasonable, since both depend on the ease of crack propagation in the material. However, parameter Q_D is of greater interest, because being a surface property, it can be correlated better with materials wear or abrasion. Wear of ceramic materials by surface scratching techniques has been widely studied. Thus, some researchers[5] have established a good relation between Q_D and abrasion resistance of ceramic glazes, or between some other scratch resistance parameter and the rate of material removal in machining advanced ceramics[13].

3.3. AESTHETIC PROPERTIES: GLOSS AND STAIN RESISTANCE

Figure 7 plots tile surface gloss versus porosity. Good correlation between both can be observed. Thus, as porosity decreases, the resulting gloss increases linearly. Surface gloss mainly depends on surface texture, porosity and refractive index. In this case, as the pieces were polished in the laboratory, suppressing the effect of industrial polishing, the texture of all the tiles was the same. However, the refractive index depends on the phases present in the pieces, whose variation, as shown in Table 1, should not modify this. Therefore, provided tile polishing is appropriately done, tile final gloss will almost exclusively be defined by tile closed porosity[3]. As this essentially depends on manufacturing process variables (composition, milling, pressing and firing), the enormous influence of processing on tile end properties is again evidenced.

Tile behaviour on exposure to staining has been evaluated by means of parameters $(\Delta E^*)_0$ (stain retention) and $(\Delta E^*)_f$ (irreversible stain retention). Both parameters also relate quite closely to tile porosity, particularly the first of these parameters, as Figure 8 shows. In principle, as porosity increases, tiles are able to retain more dirt in the pores, cracks and irregularities existing in the tile surface, altering surface colour and hence increasing the value of ΔE_0. However, samples 5 and 6 do not follow the general trend observed. In the case of sample 5, the darker colour of the original surface (L^* = 63.7 and Figure 1) partially masks the colour change that occurs when using a black staining agent. The opposite effect can be appreciated, albeit to a smaller extent, in sample 2, with a higher value of L^* (L^*=82.0 and Figure 1). Sample 6 displays large isolated round pores, which can favour partial stain extraction during initial cleaning of the pieces, reducing the value of $(\Delta E^*)_0$.

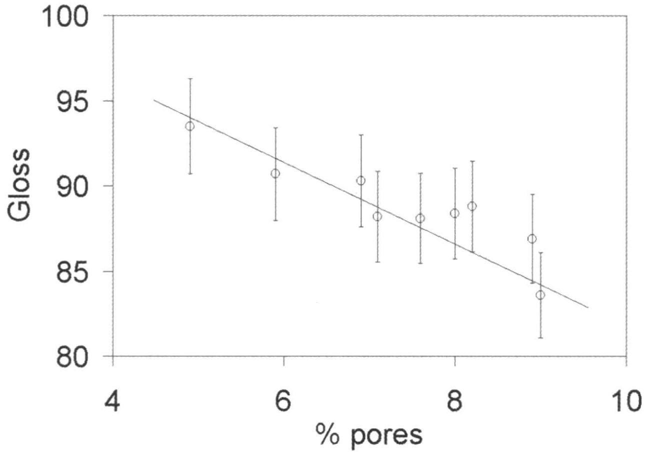

Figure 7. Influence of porosity on gloss

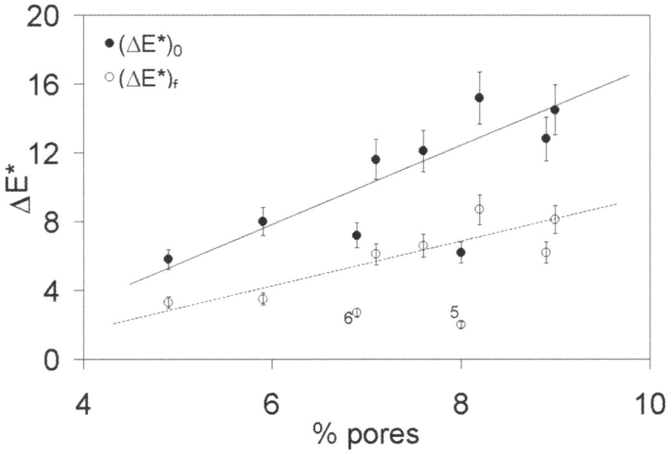

Figure 8. Influence of porosity on initial and final stain retention

Analysis of the evolution of $(\Delta E^*)_f$ with porosity exhibits a similar trend, except for the points corresponding to samples 5 and 6. Irreversible stain retention is related to tile porosity and pore morphology. Thus, whereas stain removal is relatively simple in round pores, when pores are irregularly shaped and interconnected, they are extremely difficult to clean, and yield high values of ΔE_f. Parameter $[(\Delta E^*)_0 - (\Delta E^*)_f]/(\Delta E^*)_0$ indicates tile cleanability and must therefore be related to pore morphology. All the tested samples display a value for this parameter around 0.50, except samples 5 and 6. These exhibit higher values, close to 0.65, for the reasons set out in the foregoing paragraph. The higher value obtained for sample 5 must again be related to the dark colour of the piece, whereas in sample 6, it indicates that the existing porosity is formed by pores with a morphology that facilitates cleaning (large, isolated, round pores).

Sample	β (60°)	ΔE* (initial)	ΔE* (final)	$[(\Delta E^*)_0 - (\Delta E^*)_f]/(\Delta E^*)_0$
1	88±2	11.6±1.2	6.1±0.6	0.47
2	89±2	15.2±1.6	8.7±0.8	0.43
3	87±3	12.8±1.2	6.2±0.6	0.52
4	93±2	5.8±0.6	3.3±0.4	0.43
5	88±2	6.2±0.6	2.0±0.2	0.68
6	90±3	7.2±1.6	2.7±0.2	0.63
7	91±3	8.0±1.6	3.5±0.4	0.56
8	84±2	14.5±1.4	8.1±0.8	0.44
9	88±2	12.1±1.2	6.6±0.6	0.45

Table 4. Aesthetic properties: gloss (β), stain retention $(\Delta E^*)_0$ and irreversible stain retention $(\Delta E^*)_f$ of the studied samples

3.4. POLISHABILITY. TESTS IN THE TRIBOMETER

Table V shows the results of wear tests conducted with the laboratory tribometer, using abrasive pins that contained #46 grit silicon carbide. Columns 2 and 3 list the specific wear rate of the tile (column 2) and of the grinding tool used in abrading the tile (column 3), expressed in volume loss per square meter machined and unit applied force, referenced W_P and W_M respectively. Column 4 lists the calculated ratio of the tile/pin specific wear rates, α, which represents the efficiency of the grinding process: abraded tile volume per unit abraded grinding tool volume. The purpose of the first polishing phase (levelling of the piece) is maximum material removal with minimum grinding tool wear, which is performed in harmony with the attainment of maximum polished surface quality (gloss)[14].

Sample	$W_P \cdot 10^{11}$ (m^3/N·m)	$W_M \cdot 10^{11}$ (m^3/N·m)	α (m^3_P/m^3_M)
1	6.27±0.44	5.97±0.42	1.05
2	5.69±0.40	5.54±0.32	1.03
3	8.63±0.60	8.39±0.59	1.03
4	5.98±0.42	5.60±0.29	1.07
5	4.90±0.34	4.75±0.48	1.03
6	9.12±0.64	9.03±0.63	1.01
7	4.31±0.30	4.15±0.29	1.04
8	4.90±0.34	4.23±0.30	1.16
9	4.90±0.34	4.24±0.30	1.16

Table 5. Specific wear rate of the tile (W_P), grinding tool (W_M) and their ratio (α), using #46 grit SiC abrasive

According to the literature, the wear rate of homogeneous ceramic materials basically depends on the hardness of the material, its modulus of elasticity and its toughness[15]. The determination of porcelain tile hardness by any of the traditional methods (Vickers, Rockwell, etc.) is extremely delicate, owing to porcelain tile's high microstructural heterogeneity, with abundant presence of dispersed phase. Thus, when the Vickers hardness of the samples was determined, they all exhibited similar values of 5.8-6.0 GPa. This is mainly because the test can only evaluate the hardness of the glassy matrix, which is very similar in the studied samples. On the other hand, when it was attempted to relate specific wear rate to modulus of elasticity, no clear trend was observed.

As a result of the above, it was attempted to correlate porcelain tile specific wear rate (W_P) to toughness and parameter Q_D (Figures 9 and 10 respectively). It can be observed that in both cases, the linear correlation of negative slope is acceptable, particularly taking into account the high microstructural heterogeneity of porcelain tile. It can therefore be concluded that when quartz content in the fired product increases, the material becomes more and more difficult to polish (W_P decreases), as a result of its greater resistance to brittle fracture (higher value for toughness and Q_D). Indeed, as some researchers have confirmed[14], during the first polishing phase, material removal is based on a brittle fracture mechanism of the surface, caused by the high contact pressure of the abrasive grain as it travels across the surface. Therefore, increased toughness will lead to a greater resistance to material removal.

On the other hand, the variation of parameter α (m^3 abraded tile/m^3 abraded grinding tool), hardly depends on mechanical properties, as shown in Figure 9, because in accordance with the grinding tool wear mechanism[16], material removal during polishing is associated with grinding tool wear. In fact, silicon carbide only works when its sharp edges appear at the grinding tool surface as a result of binder (matrix) wear. This is why, at the same time, it is also much easier for abrasive grain to become dislodged and for grinding tools to lose their effectiveness. This therefore means that achieving the same wear rate in tougher materials (i.e., with a larger quartz content) will impair grinding efficiency, because the industrial operating conditions will need to become more exacerbated (generally increasing polishing head pressure), with the ensuing increase in grinding tool wear.

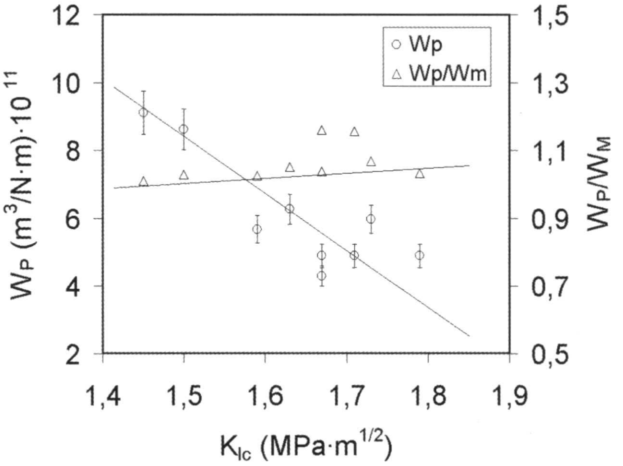

Figure 9. Influence of toughness on tile especific wear rate

Consequently, the acceleration of the polishing process can be encouraged by designing compositions with a minimum quartz content. In addition, minimising quartz content (or reducing its particle size) will concurrently enable obtaining low porosity values in the polished tiles, with the entailing enhancement of product quality (gloss and stain resistance).

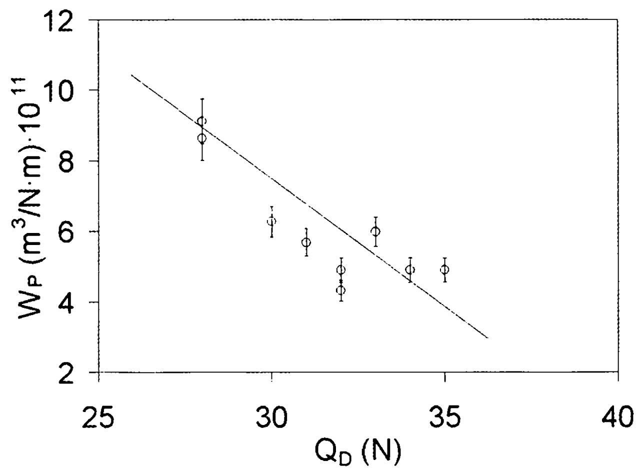

Figure 10. Influence of parameter Q_D on tile specific ware rate (W_p)

4. CONCLUSIONS

The characterisation of nine samples of industrial porcelain tile made by companies from four different countries has allowed drawing the following conclusions:

- Quartz is the major crystalline component, followed at a great distance by mullite. The range of contents of both crystalline phases is very wide in the nine studied samples (12-27%).
- Porosity of the fired tiles also ranges widely, from very low values (around 5%) to practically twice these values (9%).

Fired tile quartz content and, to a lesser extent, mullite content largely define porcelain tile mechanical properties, since they act as strengthening phases, increasing material toughness and hence mechanical strength. It has furthermore been verified that toughness correlates quite well with parameter Q_D, which evaluates resistance to flaking in a scratch test.

For the tested samples, fired tile porosity was observed to determine the quality of the polished surface, as final gloss (after polishing in laboratory conditions) and stain resistance (stain resistance and reversible staining) depended exclusively on tile porosity.

It has been verified that using a laboratory tribometer, which suitably simulates the industrial polishing operation, enables determining the wear rate of the studied porcelain tiles and grinding tools used in polishing. Tile wear rate during polishing (as well as grinding tool wear rate) correlates adequately with toughness or parameter Q_D, as the hardness of the glassy matrix that contains the strengthening phases hardly varies. Grinding efficiency does not depend on the mechanical properties of the material to be polished, since the effects of tile wear and grinding tool wear compensate each other.

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