IMPROVEMENT OF PORCELAIN TILE DIMENSIONAL STABILITY THROUGH ON-LINE MEASUREMENT OF PRESSED BODY MOISTURE CONTENT

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ABSTRACT

Greater problems of calibers have been detected in large-size porcelain tile than in other types of floor tile. A study was therefore undertaken of the effect of pressing variables on porcelain tile, red stoneware floor tile and white stoneware floor tile behaviour in the firing stage. The results show the great importance of the pressing operation in holding a given caliber in porcelain tile. A system for effective control of this operation is proposed, based on modifying maximum pressing pressure to correct the variations in spray-dried powder moisture content, which need to be measured on-line in the pressed bodies. The on-line measurement of tile moisture content when the compacts leave the press is based on the absorption of infrared radiation by the water present in the freshly pressed body. The validity of this method has been verified and it has been determined, on an industrial scale, that the maximum fluctuations of moisture content in typical tile manufacturing conditions sometimes exceed the admissible variation for this variable, which requires appropriate modification of pressing pressure to keep green tile compactness within the appropriate margins for producing a single caliber.

1. INTRODUCTION

The two most common defects associated with lack of dimensional stability in ceramic tiles are calibers and departures from rectangularity, which lead to an important loss of end product quality. Calibers involve a lack of dimensional stability between pieces, i.e., tiles that should have the same size, but in fact do not. However, departures from rectangularity are defects that affect the dimensions of each piece, and involve lack of rectangularity between sides of the same tile. Numerous studies [1-7] have shown that lack of dimensional stability in ceramic tiles is due to inadequate processing in the pressing and/or firing stages.

Indeed, lack of dimensional stability in porous wall tiles[7] is fundamentally caused by non-uniform temperature distribution in the kiln preheating zone (between 800 and 950°C), and is practically independent of green tile porosity. In industry, appropriate control of the body composition and temperature distribution in this zone of the kiln enables producing wall tiles free of dimensional defects.

In the case of non-porcelain floor tiles (known as red or white stoneware tiles, based on the colour of the fired body), lack of dimensional stability is caused by both variations in green tile porosity and non-uniformity in peak temperature distribution during firing[1-6]. Thorough control of green tile porosity in pressing[8-11]enables producing pieces with the same caliber, provided kiln operation is appropriate. When the desired uniform porosity of the green compacts is not achieved across different tiles, it is always possible to modify peak firing temperature to produce pieces of the same caliber, owing to the capacity of these materials to modify their linear shrinkage with temperature.

Greater problems of dimensional stability (particularly calibers) have been found in large-size porcelain tile than in other types of floor tile, essentially because porcelain tile green compactness is lower, while its final fired porosity is smaller. These problems are difficult to avoid in practice, as the behaviour of this type of very low porosity materials at standard firing temperatures differs from that of non-porcelain floor tile, as firing shrinkage is practically insensitive to modifications in peak firing temperature. In practice, if the end product is subjected to grinding and polishing, problems of dimensional stability can be corrected. However, such machining of glazed porcelain floor tile, whose production is steadily growing in Spain, adds a further stage to the production process, considerably increasing product cost.

2. OBJECTIVES

A series of experiments has been conducted on a laboratory and industrial scale with a view to:

- Studying the effect of variations in green tile compactness and peak firing temperature on floor tile dimensional stability, to compare the sensitivity of these materials to alterations of these variables.
- Determining the admissible maximum variation range of unfired bulk density (ΔD_{ap}^*) and pressing powder moisture content (ΔH^*), to obtain a single caliber based on the type of product, its size, kiln operation and caliber tolerance.

- Developing and fine-tuning a reliable system of on-line tile body moisture measurement at the press exit on an industrial scale, in order to improve control of the pressing operation.

3. MATERIALS, EQUIPMENT AND EXPERIMENTAL PROCEDURE

The laboratory tests were performed using three standard compositions employed in industry for floor tile manufacture: a white stoneware floor tile body (W), a red stoneware floor tile body (R), and a porcelain tile body (P). Appropriate tests were conducted on these compositions in the laboratory to determine their compaction and vitrification diagrams[12].

The moisture content of the freshly compacted pieces was measured with an infrared moisture gauge[14] [16]. The system allows on-line measurement in real time of the moisture content of each compact. The values are stored in a computer for subsequent analysis. The moisture gauge was calibrated in the laboratory in static conditions. It was then installed on an industrial press, adjusting the calibration obtained in the laboratory.

The industrial-scale experiments were performed on a standard hydraulic press[13] used for pressing tile bodies. The measurements were carried out on glazed porcelain tile bodies.

4. RESULTS

4.1. SENSITIVITY OF DIFFERENT TYPES OF FLOOR TILE TO THE APPEARANCE OF CALIBERS. COMPARATIVE ANALYSIS

Figure 1 depicts the vitrification diagrams corresponding to materials P, W and R pressed to different green compactnesses. The results have been fitted to a polynomial equation of the type:

$$\text{WA or LS} = (AD_{ap} + B)T^2 + (CD_{ap} + D)T + ED_{ap} + F \qquad \textit{eq. 1}$$

where:

LS = Linear firing shrinkage (%)

WA = Water absorption of the final product (%)

D_{ap} = Dry tile bulk density (g/cm^3)

T = Peak firing temperature (°C)

A, B, C, D, E and F = Empirical fitting parameters

As Figure 1 shows, the calculated values (lines) fit the experimental data well. The shape of these curves is the typical shape for this type of composition[2-4].

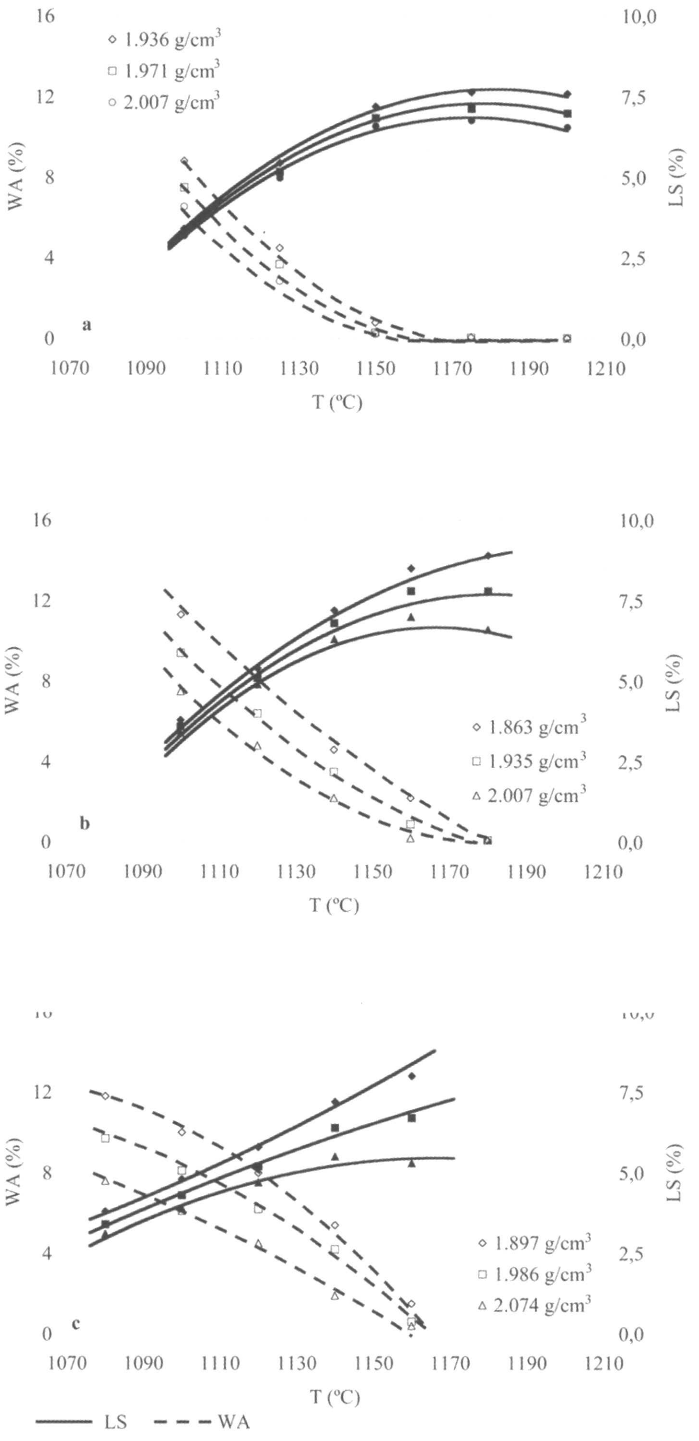

Figure 1. Vitrification diagrams of porcelain tile (a), white stoneware (b) and red stoneware (c).

For each material these equations enabled determining, as a function of water absorption, the variation of linear shrinkage with peak firing temperature, at constant compactness $((\partial LS/\partial\ T)_{Dap=constant})$, and with bulk density, at constant peak firing temperature $((\partial LS/\partial\ D_{ap})_{T=constant})$. The results are depicted in Figure 2. The shape of these curves is observed to be similar for the different types of products. The effect of peak firing temperature on linear shrinkage diminishes as porosity decreases (solid line). In contrast, the effect of tile bulk density on this property (linear shrinkage) increases as porosity decreases (dashed line).

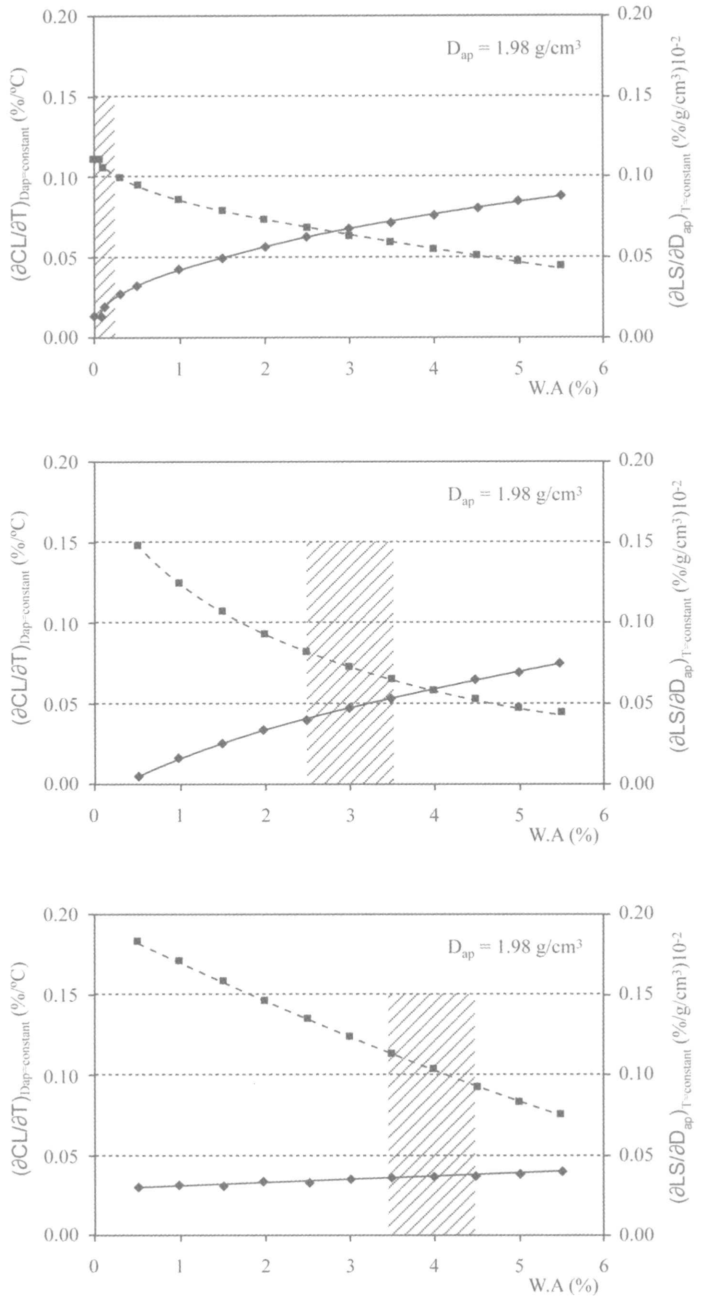

Figure 2. Sensitivity of porcelain tile (a), white stoneware (b) and red stoneware (c) to variations in bulk density and peak firing temperature.

It can be observed that for the set operating conditions and standard final porosities of each type of product (hatched area), porcelain tile linear shrinkage is very sensitive to the variation of green compactness and practically insensitive to the modification of peak firing temperature (Figure 2a). In contrast, the linear shrinkage of the other materials is quite sensitive to changes in peak firing temperature (Figures 2a and 2b). This makes it possible for an appropriate adjustment of peak firing temperature to correct the effect of a deviation in green tile compactness, while holding tile caliber. However, the greater sensitivity of these materials to peak firing temperature demands more exhaustive control of the homogeneity of this variable in the kiln cross section than in the case of porcelain tile. With regard to the sensitivity of linear shrinkage to variations in bulk density, the figures show this is quite similar in the three materials.

4.2. ADMISSIBLE MAXIMUM VARIATION OF BULK DENSITY (ΔD_{ap}^*) DURING THE MANUFACTURING PROCESS

To calculate ΔD_{ap}^* it is necessary to know the equation that relates linear firing shrinkage to green tile compactness and peak firing temperature (Equation 1) and the value of admissible maximum variation of linear shrinkage (ΔLS^*). This last variable can be calculated from the expression:

$$\Delta LS^* = \frac{t}{L_f}(100 - LS) \qquad \textit{eq. 2}$$

where:

ΔLS^* = admissible maximum linear shrinkage (%)

t = admissible maximum difference in size of two pieces to enable considering them of the same caliber (caliber tolerance) (mm)

L_f = nominal final length of the tile (mm)

LS = linear shrinkage (%)

Deriving Equation 1 and transforming the differential terms into finite increments yield an expression that relates the alteration of tile linear shrinkage during firing (ΔLS) due to possible fluctuations in dry bulk density (ΔD_{ap}) and effective peak firing temperature (ΔT) (Equation 3).

$$\Delta LS = \left[(AD_{ap} + B)2T + (CD_{ap} + D)\right]\Delta T + (AT^2 + CT + E)\Delta D_{ap} \qquad \textit{eq. 3}$$

If T and D_{ap} are replaced in this expression by nominal peak firing temperature (T_0) and unfired bulk density of (D_{ap0}), while ΔLS is replaced by the admissible maximum (ΔLS^*), defined by Equation 2, and ΔT by ΔT^*, the maximum fluctuation of effective firing temperature, the foregoing equation can be rewritten as:

$$\Delta D_{ap}^* = \frac{\Delta LS^* - \left[(AD_{ap0} + B)2T_0 + (CD_{ap0} + D)\right]\Delta T^*}{\left|AT_0^2 + CT_0 + E\right|} \qquad \textit{eq. 4}$$

This expression allows calculating the admissible maximum difference between the mean bulk density of the different pieces that enter the kiln to avoid calibers, based on the maximum variation of the admissible linear shrinkage (ΔLS^*) and differences in the effective peak firing temperature (ΔT^*) which can occur between the tiles during this operation. The values of ΔT^* depend exclusively on kiln characteristics and kiln operation (possible transverse temperature gradients and/or fluctuations of point temperature over time).

4.2.1. *Effect of the different operating variables on ΔD_{ap}**

Table 1 lists the values of ΔD_{ap}* calculated from Equation 4 for different types of product, tile final sizes, caliber tolerances and maximum variations of effective firing temperature (ΔT*). The calculations were made at the standard water absorption of the end product in each case (4% for red floor tile (R), 3% for white floor tile (W) and 0.05% for porcelain tile (P)). Two values were chosen for ΔT*, in accordance with the appearance or absence of calibers throughout the kiln cross section. It was determined that ΔT*= 3ºC corresponds to a kiln malfunction, whereas ΔT*= 1.5ºC must be considered standard operation. Obviously, ΔT*= 0 would correspond to ideal kiln operation.

Caliber tolerance (mm)	Size (cm x cm)	ΔT* = 1.5 °C			ΔT* = 3 °C		
		R	W	P	R	W	P
1	30x30	25	35	26	20	24	24
	40x40	17	23	19	12	13	17
	60x60	10	12	12	4	2	10
1.5	30x30	40	55	40	35	45	38
	40x40	29	39	30	23	29	28
	60x60	17	23	19	12	13	17

Table 1. Admissible maximum green compactness variation between tiles, ΔD_{ap}* *(g/cm³) 10³*

The results in Table 1 indicate that for the three compositions, ΔD_{ap} decreases when size, caliber tolerance and ΔT* increase, as was to be expected. For large sizes and standard kiln operation, ΔD_{ap} of the three compositions is very similar. For these sizes, if ΔT* increases, porcelain tile ΔD_{ap}* rises more than that of the red and white floor tile, due to the greater effect of peak firing temperature on the linear shrinkage of these last tiles.

These results suggest that for large sizes, the difficulty of fabricating porcelain tile is practically the same in the case of standard kiln operation, as that of making the other materials, and even smaller when ΔT* increases. This is actually not true, as the greater sensitivity of red and white stoneware linear shrinkage to peak firing temperature enables correcting possible fluctuations of mean compactness between tiles, which can not be done in the case of porcelain tile, making porcelain tile manufacture more difficult owing to the appearance of more calibers.

Although bulk density variations can be corrected during the firing stage in the case of red and white floor tiles, given the sensitivity of these compositions to peak firing temperature, the reduction of ΔD_{ap}* is so pronounced when size is increased to the necessary dimensions, that if these sizes are to be fabricated without increasing the caliber tolerance, high temperature uniformity in the firing zone is required.

4.3. ADMISSIBLE MAXIMUM VARIATION OF MOISTURE (ΔH*) DURING THE PRESSING OPERATION

With a view to determining ΔH* for the studied materials and pressing pressures used, the compaction diagrams have been determined, fitting the experimental results to an equation of the type:

$$D_{ap} = (a\,H + b)\log(P) + c\,H + d \qquad \textit{eq. 5}$$

where:

D_{ap} = Dry tile bulk density (g/cm^3)
H = Pressing powder moisture content on a dry weight basis (%)
P = Maximum compaction pressure (kg/cm^2)
a, b, c, d = Empirical fitting parameters

Figure 3 plots the experimental data and values calculated according to Equation 5 (solid line), which display very good fit. At the same pressing pressure and powder moisture content, the red floor tiles are observed to be much denser than the porcelain tiles and white floor tiles. In addition, the effect of pressing moisture on tile compactness is also much greater for the red floor tile compositions. This behaviour is due to the different nature and percentage of colloidal particles, as well as the particle size distribution of the coarsest particles (quartz, feldspar, etc.)[1] [18].

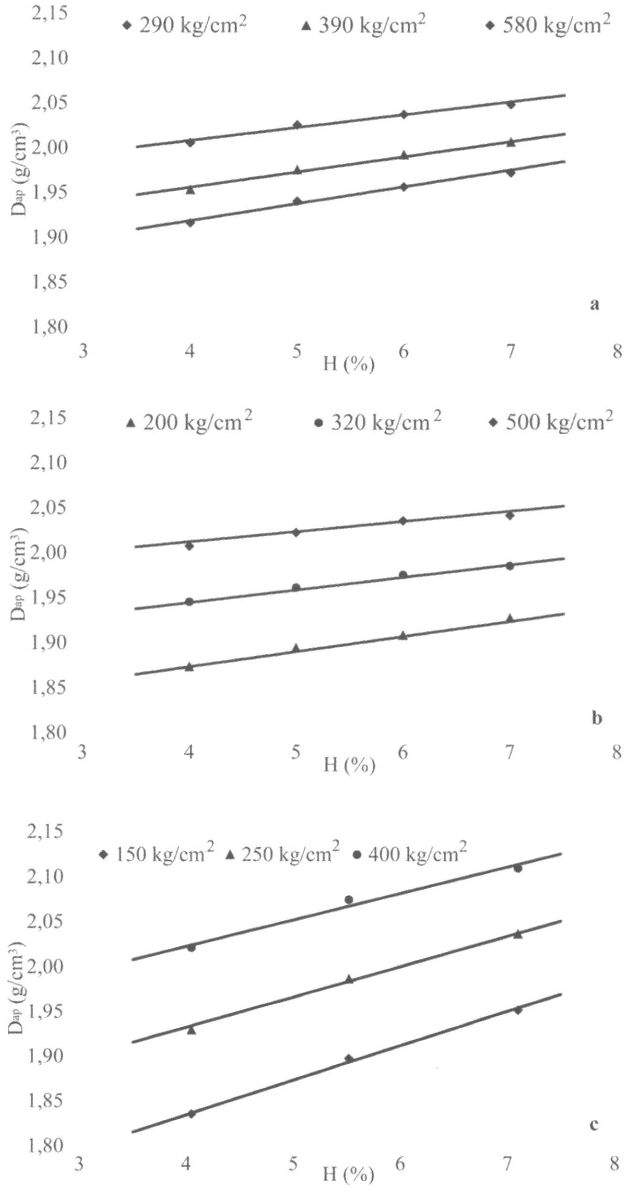

Figure 3. Compaction diagrams of porcelain tile (a), white stoneware (b) and red stoneware (c).

Following an analogous procedure to the one in point 4.2, an analytical expression has been obtained that relates ΔH^* to maximum bulk density variation (ΔD_{ap}^*) and to the maximum variation of effective pressing pressure (ΔP^*). A value of 10 kg/cm^2 has been estimated for this last parameter, based on the differences in compactness to be found between the mean compactnesses of the different bodies pressed in a single pressing run and between different pressing runs, without changing pressing powder moisture content.

4.3.1. Effect of the different operating variables on ΔH^*

The values of ΔH^* for the different studied materials have been calculated, modifying size, caliber tolerance and uniformity of peak firing temperature (ΔT^*). The results are detailed in Table 2.

Caliber tolerance (mm)	Size (cm x cm)	ΔT^* = 1.5 °C			ΔT^* = 3 °C		
		R	B	P	R	B	P
1	30x30	0.6	2.0	1.4	0.4	1.3	1.2
	40x40	0.3	1.2	0.9	0.2	0.6	0.8
	60x60	0.1	0.5	0.5	-	-	0.4
1.5	30x30	1.0	3.4	2.2	0.9	2.8	2.1
	40x40	0.7	2.3	1.6	0.5	1.7	1.5
	60x60	0.3	1.2	0.9	0.2	0.6	0.8

Table 2. Admissible maximum variation of pressing powder moisture content (ΔH^* (%))

The table shows that for the three materials analysed, ΔH^* decreases as tile final size increases. Moreover, the admissible variation in moisture content is much narrower for red floor tile (R) than for the other materials. Despite the nature of these results, especially for the red stoneware, since it would be practically impossible to fabricate tiles of only a single caliber for large tile sizes, the fact that linear shrinkage of this type of material can be altered by modifying peak firing temperature, if necessary, enables making large-size tile with one main caliber. The same can be said for white floor tile (W).

In contrast, porcelain tile poses a different problem. Thus, although it displays higher ΔH^* than the red floor tile composition, which means a smaller tendency to present calibers for this reason, the alterations in size that can take place as a result of differences in green tile compactness can not be corrected in the firing stage, since the effect of temperature on linear shrinkage at very low water absorption values is practically zero. Consequently, for these materials, the manufacture of large sizes requires increasing caliber tolerance.

4.4. ON-LINE MEASUREMENT OF FRESHLY PRESSED COMPACTS

The above indicates the need to modify pressing pressure to hold green tile compactness when pressing powder moisture content varies more than ΔH^*, particularly in porcelain tiles, if the caliber is to be maintained. In other cases it is still possible to act in order to obtain a single caliber, modifying firing shrinkage by appropriately adjusting peak firing temperature. In order to effectively achieve more or less constant tile compactness, assuming suitable press operation, it is essential for pressing powder moisture variations to be smaller than ΔH^* or to have continuous information on this variable in order to judiciously modify pressing pressure. In both cases, it is essential to continuously measure pressing powder moisture.

For this purpose, we have developed and fine-tuned a system that is able to measure this variable on-line, using an Infrared Engineering, Model MM710, moisture gauge, based on absorption of infrared radiation by the water molecules contained in a solid[14] [16]. The system is already being used successfully for measuring spray-dried powder moisture content at the spray dryer exit, and provides automatic control of the ceramic spray-drying operation[15]. However, given the singularity of the new application, it was considered advisable to run a series of preliminary experiments before installing the instrument at the industrial press.

4.4.1. Laboratory-scale experimentation. Fine-tuning of the equipment.

4.4.1.1. On-line measurement of tile bodies under static conditions. Effect of different operating conditions on moisture content measurement.

In order to fine-tune the equipment, an experiment was conducted in the laboratory, which consisted of simultaneously recording the weight loss that a freshly pressed body undergoes in ambient conditions, and the electric signal provided by the sensor during a sufficient period of time to allow the body to dry until reaching moisture equilibrium with the ambient. For this, the wet body was set on a balance, focusing the moisture sensor on the tile surface (Figure 4). This arrangement provided a simultaneous body weight loss and gauge readout.

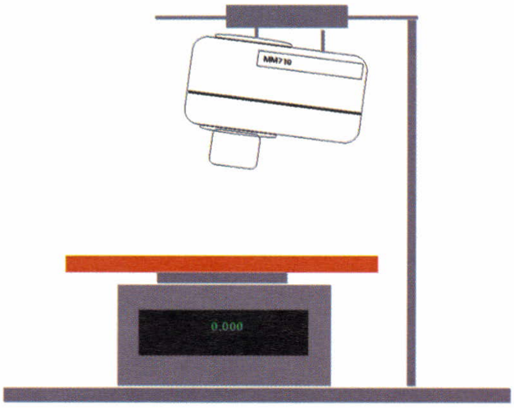

Figure 4. Measurement of body moisture content under static conditions

Figure 5 plots the moisture measurement readout during the experiment as a function of actual body moisture content. The relation between the two variables is observed to be practically linear, demonstrating the capacity of the instrument to measure moisture on-line.

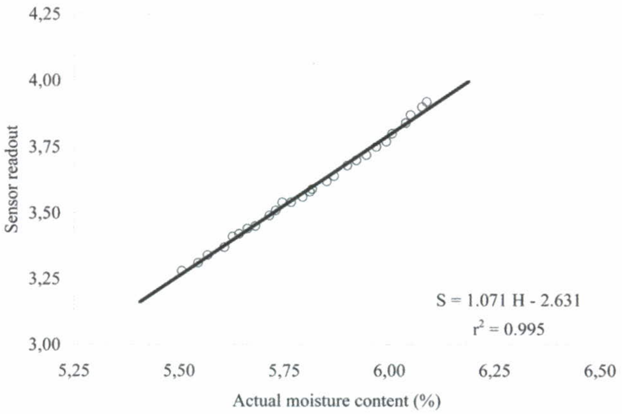

Figure 5. Relation between body moisture content and sensor readout

The same experiment was repeated for different values of ambient air relative humidity (from 60 to 45%) and temperature (from 25 to 40°C). This yielded a correlation similar to that of Figure 5, demonstrating that, in the studied range, sensor moisture measurement is independent of these variables.

The infrared sensor also has an independent cooling system that enables keeping its inner parts at constant temperature, thus compensating any possible effect of ambient temperature, or heating of system parts during instrument operation, on moisture measurement. In order to analyse the effect of gauge inner temperature on the sensor readout and to verify instrument operation in case the cooling system should not be working properly, a similar experiment was performed to the foregoing, switching off the cooling system. In this experiment, sensor temperature rose by 10°C, but the correlation between the signal recorded by the sensor and body moisture was analogous to that depicted in Figure 5, demonstrating sensor stability even when the cooling system was no longer working, at least for a variation in gauge temperature of the order of 10°C.

4.4.2. Industrial-scale experiments

4.4.2.1. In-plant installation of the system

After fine-tuning the equipment on a laboratory scale, we installed the system in an industrial plant. The system was positioned immediately after the press, specifically after the tile turning facility and before the entry of the freshly pressed bodies into the dryer (Figure 6). The sensor measurement area is a circumference with a 50-mm diameter.

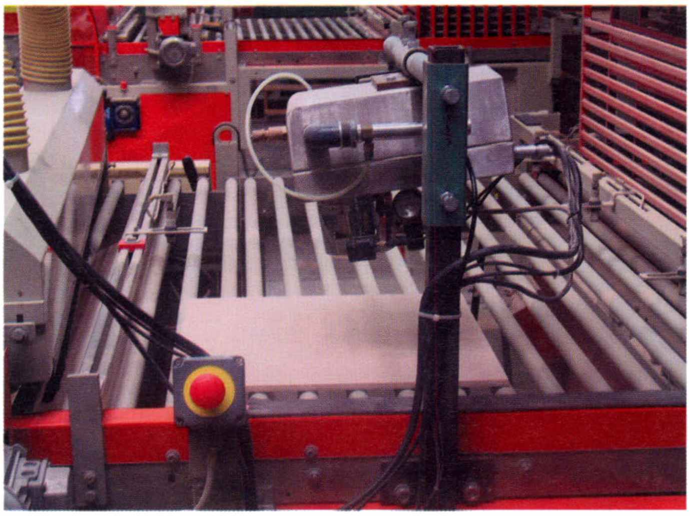

Figure 6. View of the tile body moisture measuring equipment in the production line

The measurement system is fitted with a series of photocells that supply the sensor with information on the presence of pieces in its field of measurement; when no tile travels through this field, the sensor therefore supplies no signal. When a tile enters the measurement field, the sensor starts measuring at a maximum rate of 10 measurements per second. Depending on tile size and travelling speed, the system is therefore able to provide several moisture values for each piece. Specially developed software then calculates mean moisture content of each tile based on the sensor measurements. This mean value is taken as tile moisture content.

4.4.2.2. System calibration

After positioning the gauge in the industrial facility, it was calibrated in actual running conditions. This required establishing the relation between real tile moisture content in an oven and the sensor signal.

In order to perform the calibration, it was first verified that the moisture content of the compacts determined by drying in an oven matched that of the spray-dried powder being fed into the press at that moment (Table 3). The data show that the values are very similar; the values corresponding to pressed body moisture content are slightly lower, probably because of the time elapsing from compact extraction from the press die to weighing.

Pressing powder moisture content	6.1	6.1	6.1	5.8	5.8	6.4	6.3	6.3
Compact moisture content	6.0	6.1	6.0	5.7	5.7	6.3	6.3	6.3

Table 3. Comparison between pressing powder and compact moisture content (%)

This allows using the spray-dried powder moisture value as the actual tile body moisture content, thus facilitating the calibration process. Indeed, measuring body moisture content by oven drying is much more tedious than measuring spray-dried powder moisture by oven drying. This is due to the compactness of the pressed bodies, which prolongs drying times, and the need to have a balance next to the press to weigh the body immediately after compaction. This contrasts with the spray-dried powder, which can be collected in a plastic bag without losing moisture. There is furthermore the difficulty of handling the fresh compacts, because of their size and low mechanical strength, which heightens the probability of breakage.

The industrial sensor was therefore calibrated with the spray-dried powder moisture being fed into the press, using the value indicated by the instrument when the pressed body travelled through the measuring system. The actual measured moisture content data and the values recorded by the infrared system have been plotted in Figure 7.

The figure shows that the values fit a straight line quite well, of equation:

$$H = 0.949\ S + 1.932 \qquad r^2 = 0.927 \qquad \text{eq. 6}$$

where:

H: Body moisture (%)

S: Sensor readout

The standard deviation of the values measured relative to the ones estimated from this regression for an 85% confidence range is 0.10%. This is sufficient for the required accuracy, so that Equation 6 is used as the calibration straight line of the moisture sensor.

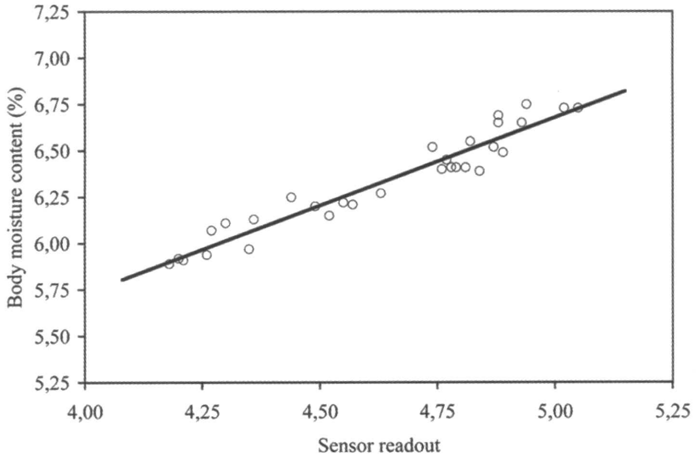

Figure 7. Calibration of the infrared moisture sensor

This calibration straight line has been obtained for a pressing powder used in the manufacture of glazed porcelain tile without through-body colouring. It was verified that when small proportions of pigment (< 0.5% by weight) were added, the calibration straight line was conserved. However, for other types of compositions or larger quantities of pigment, the corresponding calibration straight line needs to be determined, as the absorption of infrared radiation is influenced by the chemical composition and colour of the solid. It was also found that the possible modifications that occur with time in the colouring and/or chemical composition of the pressing powder, given the natural character of most of the raw materials contained in their composition, affect the calibration straight line, and need to be corrected in accordance with the detected variations.

4.4.2.3. Influence of tile compaction on moisture measurement

In this section, it was attempted to ascertain whether alterations in tile compactness modified the moisture measurement readout of the infrared sensor. For this, bodies were pressed at different pressures during a period of time in which pressing powder moisture remained constant.

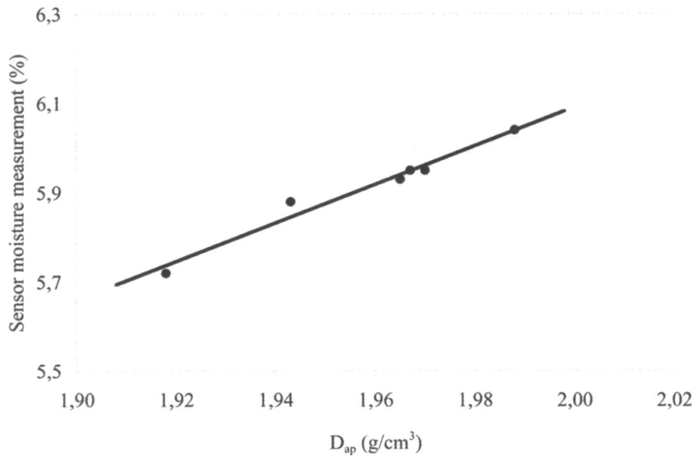

Figure 8. Influence of tile compactness on moisture measurement

Figure 8 plots sensor moisture measurement versus tile compactness. Although actual pressing powder moisture content remained constant, sensor measurement was greater when tile compactness increased.

This behaviour is due to body drying in the time elapsing after leaving the press until the bodies cross the sensor, and the effect of body compactness on the drying mechanism. In fact, the step that controls tile drying is water diffusivity from inside the piece to the tile surface, and the parameter that characterises this behaviour is the diffusion coefficient, which increases when tile compactness rises. Consequently, increasing tile compactness slows the tile drying process, making tile moisture content higher when the tile crosses the measuring system, even though tile initial moisture content was the same.

In order to reduce this effect as far as possible, it is advisable to position the moisture measurement system as close as possible to the press exit. The effect of this variation on moisture measurement is however very limited (4.31 %/(g/cm^3)) for the studied composition) and can be corrected from the fit of the experimental data shown in Figure 8.

4.4.2.4. On-line measurement of pressing moisture content. Analysis of some actual situations.

After duly calibrating the measurement system, we monitored the evolution of the moisture content of freshly pressed bodies at the press exit with time. Some of the most interesting results are set out below.

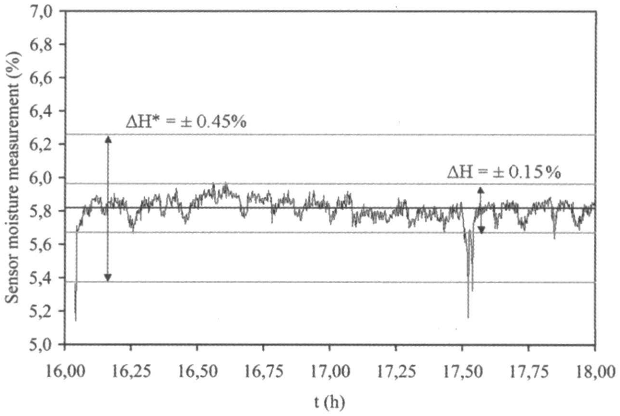

Figure 9 Evolution of freshly pressed tile moisture content

Figure 9 plots the evolution of the moisture content of newly pressed bodies during two hours, under standard press operating conditions. The figure shows that in the period analysed, moisture remained approximately constant around a value of 5.8%, with a maximum variation of ±0.15 %. This variation is less than the admissible maximum moisture variation calculated for this type of product (glazed porcelain tile), tile final size (45 x 67.5 cm) and tolerance in the caliber involved (1.5 mm), which is ± 0.45 %.

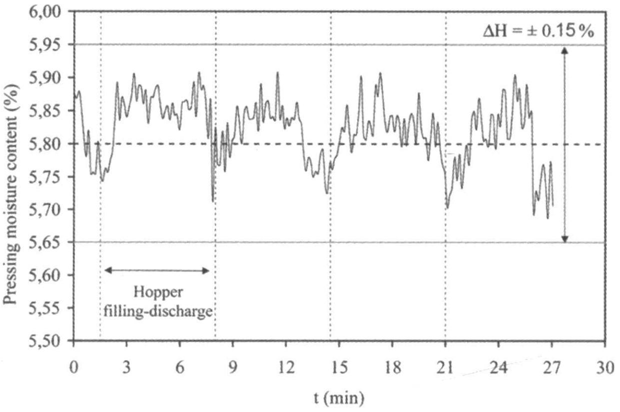

Figure 10. Moisture variations due to hopper filling cycles

Further analysis of the experimental data shown in Figure 9, focusing on a shorter period of time (30 min), yields Figure 10. This shows that under standard press operating conditions, the variation of pressing moisture with time is cyclical, and that the frequency of these cycles coincides with the filling-discharge time of the hopper that feeds the spray-dried powder into the press. The fact that hopper filling is a batch process means that the residence time of the spray-dried powder in the hopper varies, and that the moisture content of the powder exiting the hopper differs owing to drying. These fluctuations are intrinsic to the hopper filling-emptying process and, in the case at issue, were found to be approximately ±0.15%. This value basically depends on the hopper (size, covered or uncovered, etc.) and operating characteristics (filling time, etc.).

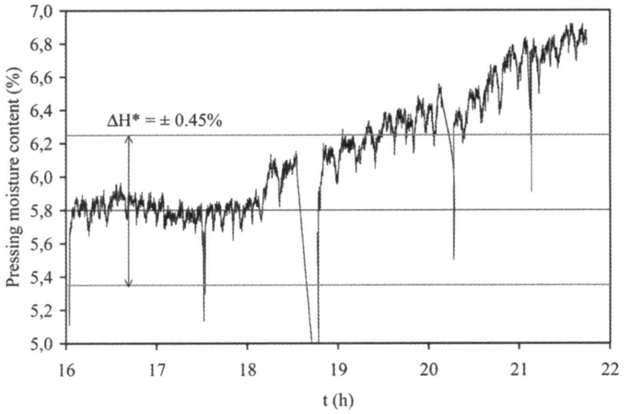

Figure 11. Evolution of pressing powder moisture in conditions producing calibers

Figure 11 plots the evolution of pressing moisture content during six hours, of which the first two hours are shown in Figure 9. It can be observed that after a certain time (18 hours), the pressing moisture content begins to increase slowly and steadily. During approximately 1.5 h, moisture content rises, though remaining below ΔH*. However, after this time pressing powder moisture continues to rise until exceeding the admissible maximum variation, causing calibers in the end products.

In view of the results obtained, an automatic press control system has been proposed, based on on-line moisture measurement and determination of ΔH* for automatic correction of maximum pressing pressure, in accordance with the powder compaction diagrams, thus reducing calibers in the end product by keeping green tile compactness constant (Figure 12).

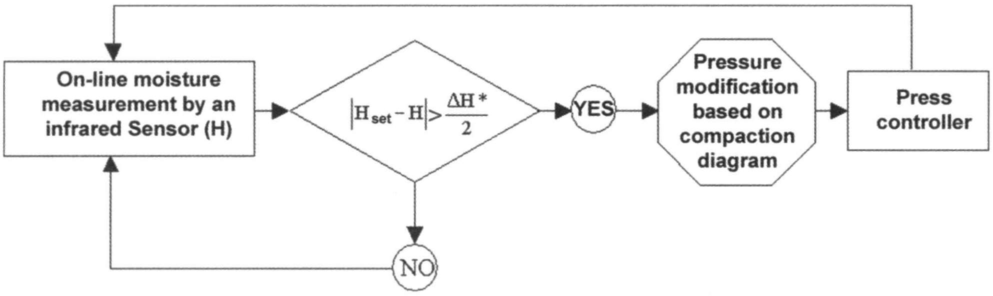

Figure 12. Schematic illustration of the proposed automatic pressing operation control

5. CONCLUSIONS

The present study allows drawing the following conclusions:

- Calibers in porcelain tiles are fundamentally due to variations in mean green compactness of the tile bodies. This is because, unlike in other floor tiles, these variations can not be corrected in the firing stage, due to the low sensitivity of linear shrinkage to peak firing temperature in this type of material.
- In order to obtain porcelain tiles of the same size, under appropriate press operating conditions, it is necessary for pressing powder moisture content to remain constant, or for moisture fluctuations to be determined in real time in order to suitably modify maximum pressing pressure, especially for large sizes, for which the maximum tolerance in the moisture variation is very low ($\Delta H^* < \pm 0.5\%$).
- Pressing moisture content can be measured on-line with sufficient accuracy by means of the system used in this study, based on an infrared sensor, which enables automatic press control in order to hold mean compactness of the bodies, thus reducing calibers, particularly in porcelain tile.

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