EVALUATION OF TACTILE SENSATION OF GLAZED SURFACES

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ABSTRACT

For consumers, among a ceramic tile's most valued characteristics are ceramic tile surface characteristics, in which, in addition to design, texture plays a key role owing to its relationship to other properties, such as slip resistance and dirt retention. Tiles are currently being made with different types of textures, there being two large groups: glossy tiles and matt tiles. In the case of glossy tiles, gloss measurement allows this property to be quantified quite well. However, matt tile classification (satin, silky,

asperous, etc.) is more complex and measurement methods are practically non-existent, touch often being used to differentiate these tiles.

Surface texture depends, among other factors, on glaze composition, which defines glaze fusibility and the presence of particles immersed in the glass, which in turn stem from the refractory materials used in the glaze, devitrifications, and reactions between the different components that occur during firing. The extent to which such processes develop depends on the firing cycle, which is why modifications in the firing stage sometimes lead to changes in tile texture and hence in some tile properties.

In this study, tiles with different textures were prepared and classified according to their degree of asperity by tactile evaluation, both by experienced tactile evaluators and by personnel inexperienced in tactile evaluation. The feasibility of using different simple measurement methods to assess surface texture was studied. Finally, the surfaces were characterised by rugosimetry, the parameters being defined that best reproduced tactile sensation.

1. INTRODUCTION

For consumers, among a ceramic tile's most valued characteristics are ceramic tile surface characteristics, in which, in addition to design, texture plays a key role owing to its relationship to other properties, such as slip resistance and dirt retention. Tiles are currently being made with different types of textures, there being two large groups: glossy tiles and matt tiles. In the case of glossy tiles, gloss measurement allows this property to be quantified quite well. In contrast, matt tile classification (satin, silky, asperous, etc.) is more complex and measurement methods are practically non-existent, touch often being used to differentiate these tiles However, tactile evaluation of a texture is a subjective sensation in whose perception, in addition to temperature and ambient humidity, other factors come into play, which depend on each particular individual, such as skin moisture content, pressure exerted on the surface and even the angle during friction movement [1][2][3].

Surface texture depends, among other factors, on glaze composition, which defines the amount of glassy phase, melt viscosity, and presence of particles immersed in the glass, which in turn stem from the refractory materials used in the glaze, devitrifications, and reactions between the different components that occur during firing. In addition, the modifications of some process variables, such as glaze particle size, degree of deflocculation, and firing temperature give rise to changes in the tile that are sometimes hardly quantifiable by tactile evaluation [4][5][6].

This study sought to objectively quantify such a subjective characteristic as the tactile sensation of tiles with matt glazes. To do so, tiles with different textures were prepared and classified according to their degree of asperity by tactile evaluation, both by experienced tactile evaluators and by personnel inexperienced in tactile evaluation. The feasibility of using different measurement methods to evaluate tactile sensation was studied, a roughness parameter being obtained that reproduced tactile sensation.

2. EXPERIMENTAL

2.1. MATERIALS

To perform the study 17 test pieces (referenced M1 to M17) were prepared with matt glazes of different composition that gave rise to a wide range of textures, from more asperous and rough to more even and smoother textures. Furthermore, to study the effect of some process variables on tactile sensation, two additional pieces were prepared from composition M17, in one increasing particle size from 0.5 to 2% on a 45μm sieve (referenced M17G) and, in the other, lowering firing temperature from 1210 to 1185 °C (referenced M17T).

2.2. SURFACE CHARACTERISATION

Surface characterisation was performed by tactile evaluation of the texture by two groups of evaluators and by using different instrumental measurement methods. Simple methods (gloss and slip resistance measurement) and complex methods (roughness tester) were used. Observations were also made by scanning electron microscopy.

2.2.1. TACTILE EVALUATION

The pieces were classified according to their degree of asperity by tactile evaluation by a group of 8 persons experienced in this type of evaluations and by another group of 8 persons who were, however, inexperienced in this regard. In both cases, the tactile evaluation of the pieces was made individually.

2.2.2. GLOSS DETERMINATION

Glazed surface gloss was determined using a reflectometer and measurements were performed at an angle of 85º, 60º, and 20°.

2.2.3. DETERMINATION OF SLIP RESISTANCE

Slip resistance was determined using the following devices:

<u>BOT-3000E tribometer</u>

This device consists of a self-propelled tester that travels at a constant rate (20 cm/s) across a test piece surface (Figure 1a). The apparatus drags an SBR rubber slider of Shore hardness A 95±3 loaded with a weight that allows application of a normal force of 21.3N. Based on the normal force exerted by the slider–load assembly (FN) and the force required to move the device (FR), the value of the dynamic coefficient of friction (DCOF) is calculated.

<u>Tortus® tribometer</u>

This instrument also consists of a self-propelled apparatus that travels at a constant rate (17 mm/s) across a test piece surface (Figure 1b). This device impels a cylindrical 4S rubber slider of hardness IRHD 96±2 that holds a weight of 200g. The dynamic coefficient of friction is calculated as quotient of the measured friction force and weight borne by the slider.

Friction pendulum

This consists of a pendulum with an arm length of 510 mm, which holds a rubber slider of about 76x25 mm (Figure 1c). The height of the device is adjusted such that the slider (rubber of hardness IRHD 59±4 or 96±2), which is subjected to a maximum load (FNm) of 22 N, is held in contact with the surface over a distance of 124 mm. The slider runs across the surface at a mean angle of 26±3º, grazing it with one of its slightly bevelled, 76-mm-long edges.

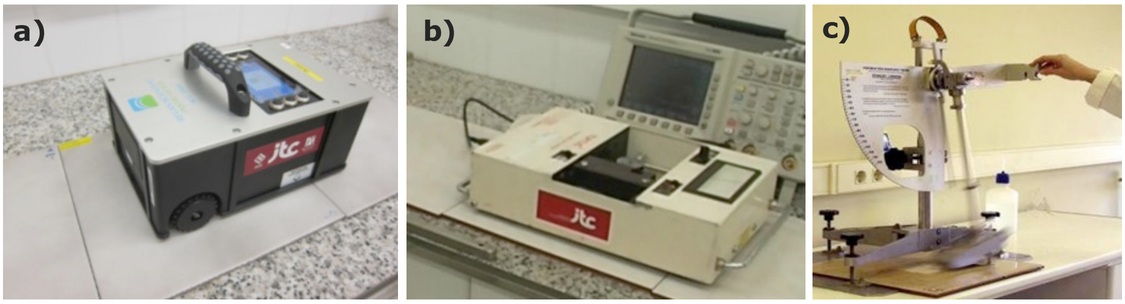


Figure 1. *Devices used to determine slip resistance: a) BOT-3000E tribometer, b) Tortus® tribometer, and c) Friction pendulum.*

2.2.4. DETERMINATION OF ROUGHNESS PARAMETERS

This test was conducted with a HOMMELWERKE model T8000 roughness tester, using a diamond tip pick-up of 90º curvature and 5µm radius. A topography made up of 80 profiles, 4.8 mm long, with a 60µm spacing, thus covering a surface area of 4.8x4.8 mm, was obtained on each studied surface. The roughness parameters were calculated using a cut-off length of 0.8 mm.

2.2.5. SCANNING ELECTRON MICROSCOPY (SEM)

Test piece surface texture was observed by scanning electron microscopy using the backscattered electron signal, which provides information on the topography of a sample.

3. RESULTS

3.1. SURFACE TACTILE CLASSIFICATION

The tactile classification according to surface degree of asperity was carried out by two groups of persons, one experienced in this type of evaluations and the other inexperienced in this regard. Table 1 details the classification, from smoothest (1) to most asperous (19) texture rating, by both groups of evaluators. To establish the position of each test piece, based on each person's rating, the number of times that the rating was repeated in the same position was calculated, the rating with the greatest number of repeats being assigned the definitive classification.

Position	Inexperienced evaluators		Experienced evaluators		Position	Inexperienced evaluators		Experienced evaluators	
	Piece	No. of repeats	Piece	No. of repeats		Piece	No. of repeats	Piece	No. of repeats
1	M2	3	M10	7	**11**	M5	3	M13	3
2	M10	3	M2	5	**12**	M17	3	M17	3
3	M8	2	M8	5	**13**	M14	2	M5	3
4	M11	3	M11	4	**14**	M13	2	M14	3
5	M7	3	M3	6	**15**	M15	3	M15	4
6	M3	5	M7	8	**16**	M17T	2	M1	3
7	M9	5	M9	5	**17**	M1	4	M17T	4
8	M4	2	M4	4	**18**	M17G	3	M17G	4
9	M16	2	M16	5	**19**	M12	8	M12	7
10	M6	5	M6	3					

Table 1. *Evaluator classification according to tactile evaluation and number of repeats.*

It may be observed that the classification provided by both groups of evaluators was similar, though it did not coincide. Note that, though the classification performed by the experienced persons exhibited a greater number of repeats than that of the inexperienced persons, there was a certain scatter among the ratings by this group, evidencing rating subjectivity. In addition, the scatter was more pronounced in the test pieces with a more asperous texture, these being the ones that exhibited the lowest number of repeats, which made it difficult to classify them. Hereinafter, the rating by the experienced group was taken as the classification.

3.2. USE OF SIMPLE MEASUREMENT METHODS FOR EVALUATING TACTILE SENSATION

First, the feasibility of using different simple measurement methods that could be used in-plant to evaluate the tactile sensation of glazed surfaces, such as gloss and slip resistance, was studied.

3.2.1. GLOSS DETERMINATION

Gloss was determined first, it being one of the simplest properties to measure on which texture has a great influence [7]. In the case of glossy surfaces, this is a determining measurement, whose sensitivity allows small variations in gloss to be detected. It was therefore verified whether, in the matt test surfaces, the gloss determination also enabled the tactile sensation to be evaluated.

The gloss values obtained for the samples, according to the order established in the classification in Section 3.1, are plotted in Figure 2. The plotted measurements were made only at light incident angles of 60 and 85º, which corresponded to the optimum specular geometries for surfaces with medium and low gloss [8][9]. The measurements obtained at an angle of 20º are not included, owing to the similarity between all resulting values.

The surfaces rated rougher or more asperous (M9 to M12 in the figure) yielded similar low gloss values at the two angles and lay in a range of 0.1 to 16 gloss units. In the case of the pieces with smoother textures (M10 to M7), a different trend was observed, as they exhibited higher gloss and the gloss values obtained for both test angles were different, the measurement made at 85º always being higher.

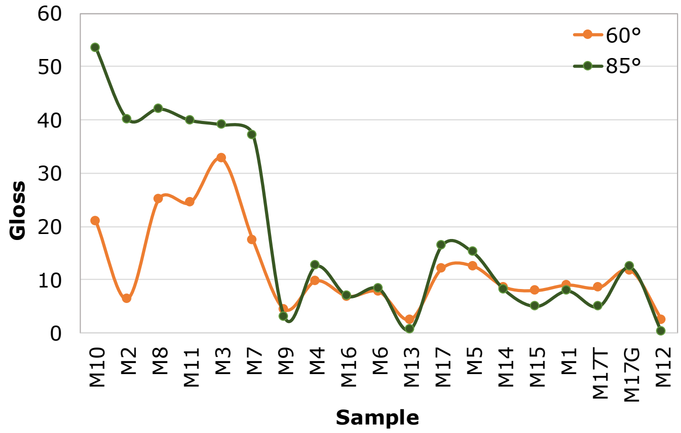


Figure 2. *Gloss measured at 60 and 85º angles for all test pieces, ordered according to their tactile classification.*

With a view to ascertaining why some glossy pieces exhibited different gloss values at the 2 measured angles, whereas others yielded very similar values, the surface of 3 samples was observed by SEM:

- M2, which exhibited much higher gloss at 85º than at 60º.
- M3, which exhibited similar high gloss values at the 2 angles.
- M9, which exhibited similar low gloss values at the 2 angles.

The micrographs obtained for the three pieces (Figure 3) show that their surface texture was different. Thus, M3 displayed a very smooth surface that justified similar high specular reflection of incident light at both measurement angles. In contrast, M2 displayed a flat surface texture with a certain roughness, which caused light to scatter (low gloss) at 60º, whereas at a grazing angle (85º) the amount of reflected light increased, yielding a higher gloss value. Finally, M9 displayed a surface texture with a much greater roughness, which caused light to scatter at every measurement angle, yielding low gloss values.

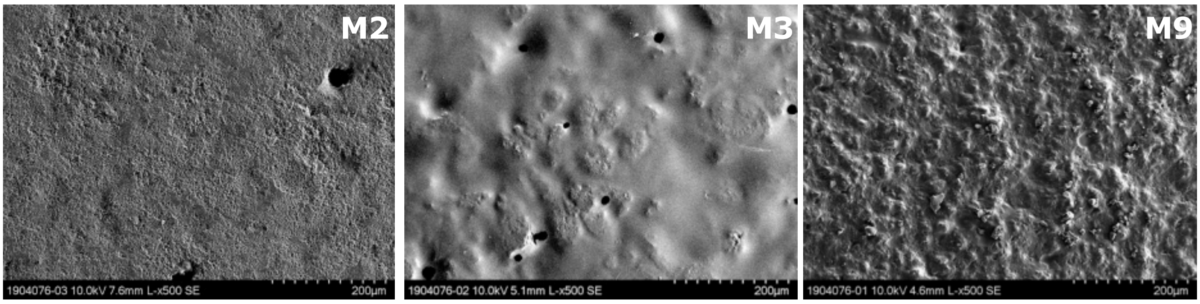


Figure 3. *Surface micrograph of samples M2, M3, and M9.*

Comparison of the gloss values shows that it was only possible to classify the samples in two groups, namely in terms of a smoother or more asperous texture. However, given the similarity between the gloss values obtained within each group, this property could not be used to order the samples according to tactile sensation.

3.2.2. DETERMINATION OF SLIP RESISTANCE

The feasibility was then studied of using slip resistance tests to evaluate tactile sensation, as the two properties are related to surface texture [10]. To quantify slip resistance, different measurement parameters are used depending on the method used for determining these. In this study, given their simplicity, the Bot-3000 E and TORTUS® dynamic linear tribometers, which allow determination of the dynamic coefficient of friction (DCOF), were used in addition to the friction pendulum to measure the pendulum test value (PTV). All measurements were made on dry test pieces to reproduce the conditions under which the surface tactile evaluation was carried out.

Initially, with a view to verifying the feasibility of using the BOT method, samples with very different textures were measured (Figure 4a). The sensitivity of the method was verified to be very low (the difference between the DCOF of the smoothest (M10) and the most asperous (M1) piece was only 0.09), thus preventing this value from being correlated with tactile sensation.

In the case of the TORTUS method, measurements were made in different conditions (different weights and type of rubber), in order to obtain a sufficiently high difference between the DCOF of the pieces located at each end of the classification (most asperous and smoothest texture). The DCOF values obtained under the best test conditions, consisting of using a silicone slider bearing a load of 100 g, have been plotted in Figure 4b. As with the BOT method, the smoothest surfaces exhibited higher values than the most asperous surfaces, though in this case sensitivity was greater, a difference of 0.46 between M10 and M1 being obtained. However, high scatter was observed among the DCOF values, preventing their correlation with tactile sensation.

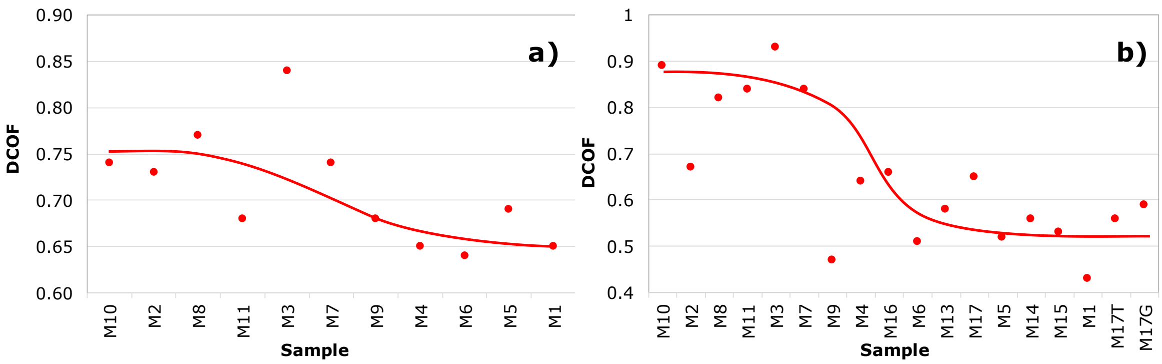


Figure 4. *Dynamic coefficient of friction: a) BOT-3000E and b) TORTUS.*

Figure 5 shows that the PTV values obtained with the dry friction pendulum were lower for the surfaces with the smoothest than with the most asperous textures. Although the values displayed a good trend with less scatter than in the previous methods, the difference in values did not allow this method to be used for evaluating tactile sensation, evidencing the difficulty of measuring this "property" and explaining the non-existence of simple methods for evaluating it.

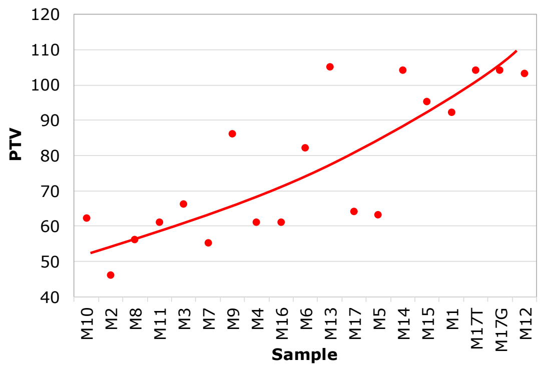


Figure 5. *PTV determined with the friction pendulum.*

3.3. USE OF COMPLEX MEASUREMENT METHODS FOR EVALUATING TACTILE SENSATION. ROUGHNESS TESTER

In view of the impossibility of evaluating tactile sensation with simple methods, it was decided to try roughness parameters, as they quantitatively describe the surface profile and are representative of the surface [11]. Thus, this part of the study examined which topographic parameters better evaluated test piece tactile sensation. Surface topographies were obtained using a roughness tester that provides 34 roughness parameters. By way of example, Figure 6 shows 3 topographies, corresponding to a smooth surface and two rough surfaces.

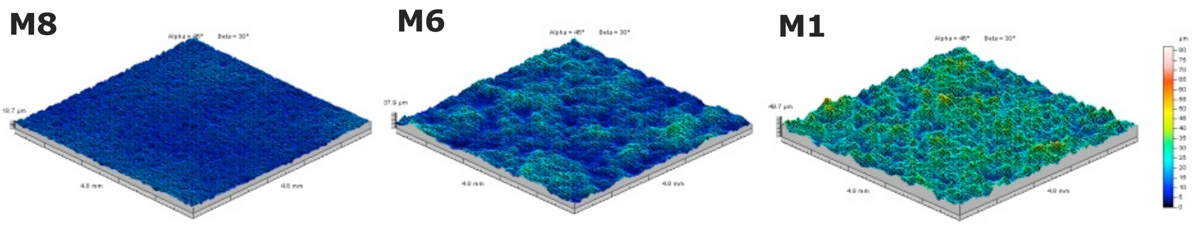


Figure 6. *Topographies of samples M8, M6, and M1.*

Each of the 34 parameters was plotted as a function of tactile sensation and those parameters were selected that exhibited a reasonable variation with the so-called "property", namely Ra, Rq, Rz, Rt, RzISO, Rp, Rpm, λa, and λq. In order to perform a second selection, the parameters were plotted against each other to analyse whether there was any relationship between them, following a procedure analogous to that used in a previous study [10], and the coefficient of regression (r^2) of the linear fit was obtained. By way of example, Figure 7 shows the graph and linear fit obtained for parameter Ra (mean roughness) versus Rt (vertical distance between the highest peak and the deepest trough in the roughness profile). The coefficient of linear regression close to 1 and the graph itself indicate that both parameters were directly related and that both exhibited the same variation with tactile sensation. Similarly, the fits to linear regression lines of parameters Ra-Rq-Rz-RzISO displayed coefficients of correlation of 0.98 or higher, so that the trend with tactile sensation in all of them could be represented by a single parameter, in this case Ra (Figure 7b).

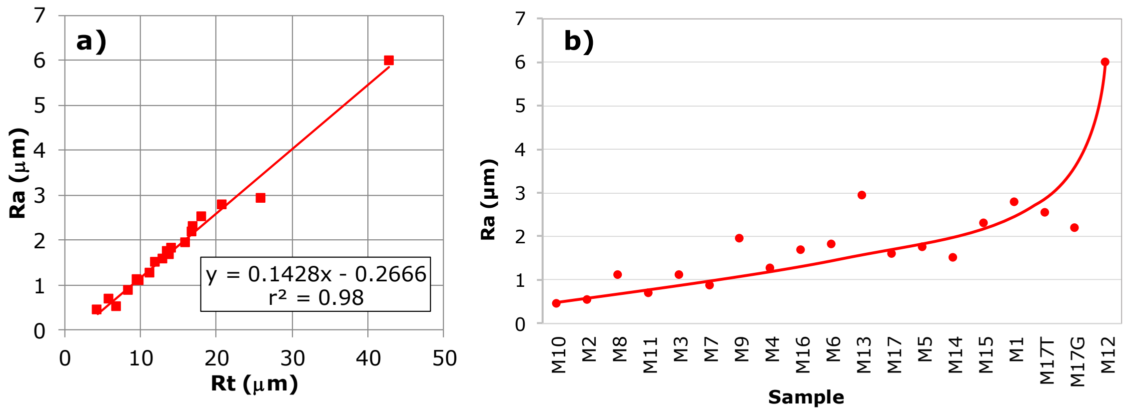
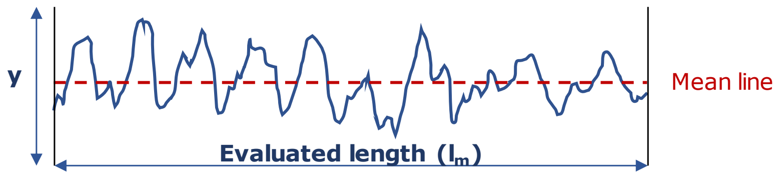


Figure 7. *a) Relationship between roughness parameters Ra and Rt. b) Variation of parameter Ra for the test samples according to the classification.*

Ra is the most representative parameter of mean surface roughness and is obtained by the arithmetic mean of the absolute values of the distance of the points making up a profile to a mean line (Figure 8), according to the equation:



$$R_a = \frac{1}{l_m}\int_0^{lm} |y(x)dx|$$

Figure 8. *Obtainment of parameter Ra from the roughness profile.*

The trend observed for mean roughness (Ra) matched the tactile sensation of the smoothest surfaces (M10 to M7), though a narrow Ra range of variation (between 0.43 and 1.10 μm) was obtained. In contrast, the most asperous surfaces (M9 to M12), which exhibited less agreement in the classification order, displayed a wider range of values (between 1.26 and 2.78 μm) and greater scatter.

Parameter Rp (distance of the highest profile peak to the mean line) and Rpm (mean distance of the peaks making up the profile to the mean line) were also related, so that their variation with tactile sensation was represented by parameter Rp (Figure 9b). The resulting trend was very similar to that of mean roughness (Ra), accentuating the differences between the most asperous textures, and decreasing those with the greatest smoothness.

The two λ parameters (λa, or profile mean waviness, and λq, root mean square of profile mean waviness) also displayed a direct relationship to each other, which allowed λa to be used as representative of both. Figure 9b shows a very good relationship between this parameter and tactile sensation, with very little scatter in the values, except for samples M12, M3, M13, and M14, and reasonable sensitivity across the test range, so that this parameter seems to be able to evaluate tactile sensation

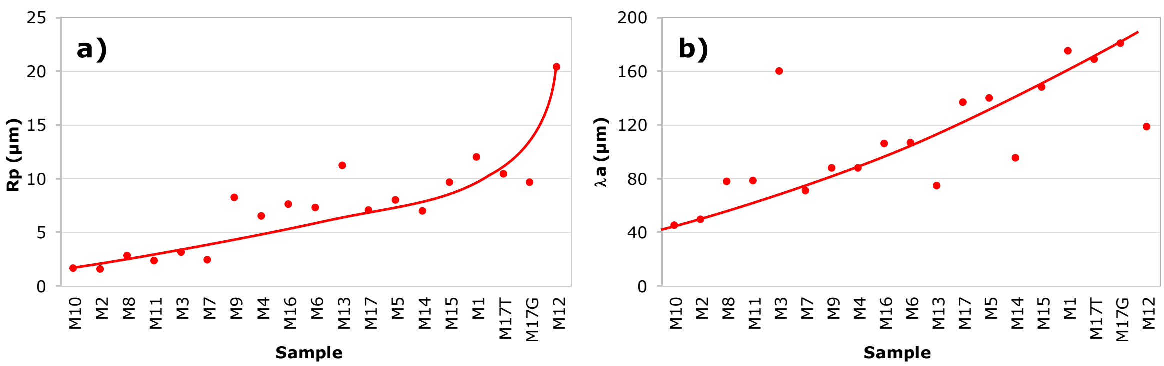


Figure 9. *Variation of parameters: a) Rp and b) λa for the test samples according to the classification obtained.*

Parameter λa is calculated from mean roughness (Ra) and profile mean slope (Δa), according to equations:

$$\lambda_a = 2\pi \frac{R_a}{\Delta_a} \qquad \Delta_a = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{\Delta y_i}{\Delta x_i}\right|$$

In addition to peak–valley distance, this parameter takes into account peak slope and, unlike parameters Ra and Rpm, the profile dimensions relating to peak height as well as those relating to peak smoothness are also used in calculating this parameter, as shown in Figure 10. Both factors are involved when the usual movement of evaluating by touch is made. That is why the values for λa aligned according to an ascending trend from the smoothest to the most asperous texture, reproducing quite well the tactile classification obtained by the experienced evaluators.

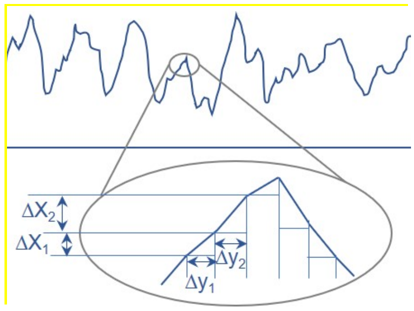


Figure 10. *Obtainment of parameter Δa from the roughness profile.*

However, as already noted, there were four samples (M3, M12, M13, and M14) whose λa values lay outside the observed trend. In order to better understand the reasons for these results, their microstructure was observed by SEM.

Figure 11 shows micrographs of M3, which had an abnormally high λa value, and of M11 and M7, positioned next to M3 in the classification, whose λa values lay on the trend line. It may be observed that M3 displayed a very smooth surface with round areas exhibiting waviness with a mean slope (Δa) that was very low (0.04 rad), yielding a high λa value. In contrast, M11 and M7 displayed more abrupt surfaces with fewer fused areas in which waviness mean slope was higher (0.06 and 0.08 rad), leading to lower λa values.

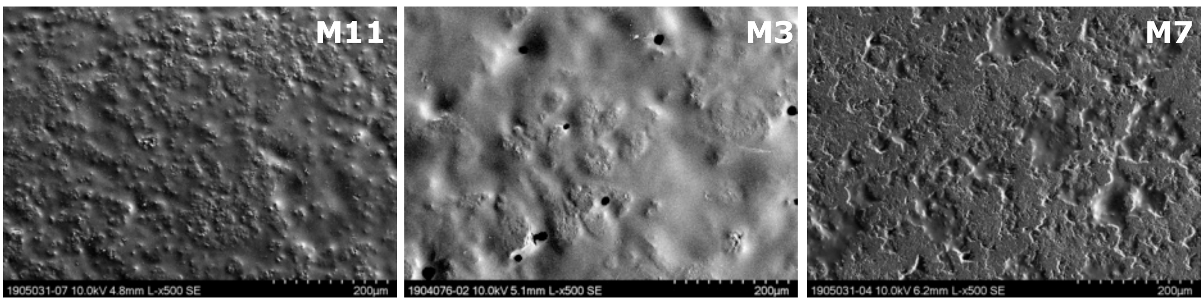


Figure 11. *Surface micrographs of samples M11, M3, and M7.*

Figure 12 shows micrographs M12 and M13, which were of the same type as M14 (not included for the sake of space). It may be observed that very rough surfaces with a very abrupt profile and very high mean slopes (0.32 and 0.25 rad) were involved, therefore leading to lower λa values than expected by touching. By way of comparison, Figure 12 also includes a micrograph of M15, positioned between M12 and M13 in the classification, whose λa value lay on the trend line. A much less rough surface than the previous ones is observed, with a lower mean slope (0.10 rad), leading to a higher λa.

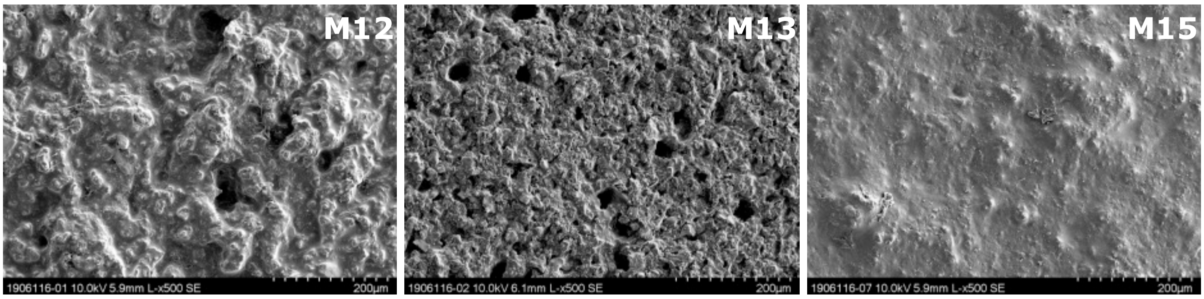


Figure 12. *Surface micrograph of samples M12, M13, and M15.*

To round off this section, Figure 13 shows the appearance of the M17 test pieces, in which glaze particle size was increased (sample M17G) and firing temperature was decreased (sample M17T). The changes in texture of these pieces matched the trend in Figure 9, so that parameter □a may be deemed appropriate for evaluating tactile sensation when process variables are modified. The surface micrographs reveal that modifying the two variables led to reduced glaze spread, giving rise to higher values of Ra (2.52 and 2.18 compared to 1.58 µm) and a higher slope value in the case of sample M17T (0.13 rad) and similar slope value in sample M17G (0.10 rad) resulting in more asperous textures. The modification of surface texture was more evident in the case of M17T, as the micrographs revealed more noticeable variations in slope than in surface roughness.

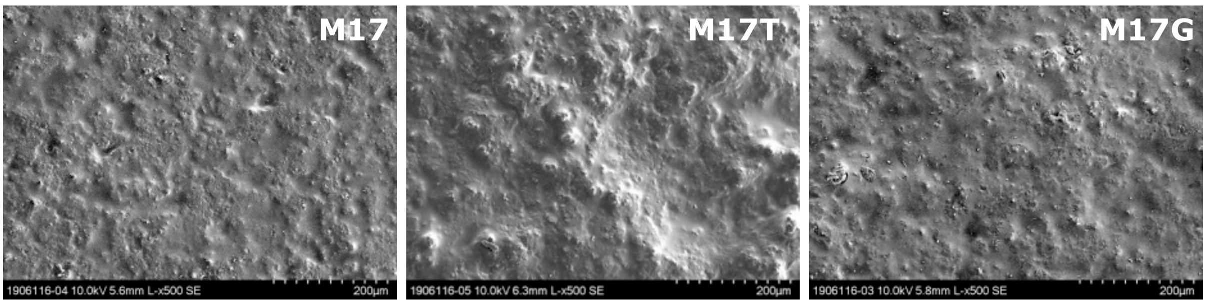


Figure 13. *Surface micrographs of samples M17, M17T, and M17G.*

4. CONCLUSIONS

The study allows the following conclusions to be drawn:

- The use of touch to classify or differentiate glazed tile textures entails a certain subjectivity, even when performed by experienced evaluators, as the scatter in the evaluators' resulting classification revealed. The scatter was even higher in evaluating a surface with an asperous texture.
- Gloss was an inappropriate property for evaluating tactile sensation and attempting to classify matt glaze surfaces.
- Slip resistance did not correlate with the tactile sensation of the test pieces, indicating that other factors also affected this evaluation.
- Of the roughness parameters, λa yielded a very similar tile rating to that obtained by tactile evaluation. This parameter takes into account peak–valley heights as well as peak slope and is able to evaluate changes in some process variables.

5. REFERENCES

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