EVALUATION OF THE ABRASIVE WEAR OF CERAMIC TILE SURFACES BY ISO 10545 AND UNE 138001 STANDARDS

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ABSTRACT

ISO 10545 defines the PEI method as the standard test to determine surface wear resistance for ceramic tiles. However, the PEI method does not provide the real conditions of wear, as the abrasives are more aggressive than the day-by-day use of ceramic tiles. On the other hand, the UNE 138001 standard specifies the same equipment as ISO 10545 but with different abrasives. For the wear test, the ISO 10545 uses corundum as abrasive (Mohs = 9), water and steels balls. The UNE 138001 uses quartz (Mohs = 7) and rubber with a predefined load. The UNE 138001 standard is close to the real condition of ceramic tile use, where shoe soles and sand friction and wear the tile surfaces. Therefore, the aim of this work was to compare the wear of nine different ceramic surfaces according to the ISO 10545 and UNE 138001 standard methods. Glossy, polished, satin, embossed, covered with corundum and with grits glazed surfaces, and polished, natural, and decorated unglazed surfaces were tested. The samples were subjected to the abrasion test by both methods, and the brightness, mass loss and roughness of the surfaces were determined every 25 revolutions up to 1250 revolutions. As a result, mass loss has a linear relationship with the number of revolutions, and the angular coefficient is higher for the ISO 10545 method for all surfaces. Gloss decreases exponentially with the number of revolutions for both methods, and the modulus of the gloss × revolution is two to three times higher for the UNE 138001 method for all surfaces. The reduction in gloss is more intense for the same number of revolutions. There was no relationship of roughness with the number of revolutions in the wear test (R^2 not significant). However, roughness increased for smoother surfaces and decreased for rougher surfaces in both methods. Although the UNE 138001 method is closer to the real conditions of ceramic tile use, the change in surface gloss caused by this test is more intense than ISO 10545, probably due to the load used on the rubbers in contact with the ceramic surface.

1. INTRODUCTION

Ceramic tiles are useful materials that can be used to cover several surfaces due to their versatility. However, considering floor coverings, the requirements for performance are rigorous. Ceramic floor tiles must meet standardized criteria for surface abrasion resistance, as established by the ISO 13006 standard [1], following the PEI classification. But some studies [2] showed that the PEI test does not replicate the real performance of the floor tile during its use.

The ISO 13006 standard [1] method defines steel spheres and corundum as abrasives and water as medium to simulate the abrasive wear on ceramic tile surfaces. The use of corundum, a hard material (Mohs = 9), and water differ substantially from the real conditions of ceramic tile use. On the other hand, the UNE 138001 standard method [3] specifies quartz (Mohs = 7) as abrasive material and rubber under a specific load to simulate the abrasive wear on the surface of the tiles, a condition closer to the real use of the tiles.

According to Silva et al. [2], the UNE 138001 method [3] was conceived as a simple, low-cost and robust method to be used as an international reference for abrasive wear. In the UNE method, the procedure for determining the real wear mechanisms was changed regarding the ISO 10545 standard [4]. The abrasive material was changed from corundum to quartz and the changes in gloss and surface texture were considered for the evaluation of tile wear.

The NBR 13818 [5] (discontinued) and ASTM C1895-19 [6] standards for determination of the Mohs hardness were cited in the UNE method. These test methods cannot provide an accurate assessment of the performance of ceramic tiles in everyday use despite providing a quantitative measure of the product's hardness.

There are few studies and analytical techniques to adequately quantify the performance of ceramic tiles, either using the intrinsic properties of the material or analyzing the construction system as a whole. Currently, there is no universal specification standard for ceramic products. Each ceramic company adopts its own specification guidelines.

According to Kim [7], understanding pedestrian behaviors and the impact of their traffic on floors is an area lacking concepts and methodological studies. The constant flow of pedestrians can lead to changes in the floor surface, due to factors such as aging, corrosion, dirt and maintenance [8]. This results in progressive wear that affects the performance of the ceramic surface [7].

The wear process gradually removes material from the surface of the ceramic tile, revealing, over time, irregularities and porosities in the vitreous layer of the glaze. These exposed porosities tend to retain dirt, facilitating its accumulation on the surface [9].

Therefore, this work aimed to study the determination of the wear resistance of ceramic tile surfaces by two standard methods, trying to define the best method for product specification. The change in roughness, gloss and mass loss of nine types of ceramic surfaces was analyzed during the wear caused by each method.

2. MATERIALS AND METHODS

Nine ceramic surfaces for use on floors were selected. The characteristics of the surfaces are described in Tab.1.

Typology	Surface finish
Glazed tile	Glossy
Glazed porcelain tile	Polished Satin Covered with corundum Covered with grits
	Embossed
Unglazed porcelain tile	Polished Natural Decorated

***Table 1**. Ceramic tile surfaces*

The wear, carried out under laboratory conditions, followed the procedure according to ISO 10545 [4] and UNE 138001 [3] standards. An abrasimeter (Gabrielli) was used and the number of revolutions was adjusted in accordance with each specific standard. Tests were performed at 25-revolution intervals on all surfaces up to 1250 revolutions on the same part of the sample. Five specimens were tested for each ceramic tile surface of Tab.1. The average, standard deviation and variability between samples were determined.

The analysis of wear after a 25-revolution interval was performed by determining the following characteristics:

a) Mass loss in each abrasion cycle after 25 revolutions. A scale with 0.001 g resolution was used;

b) Gloss was measured at 60° using a glossmeter (Imbotec). A guide was used for positioning the equipment at the same place on the surface of the tiles;

c) Roughness was evaluated using a mechanical contact profilometer (Mitutoyo SJ-210). Five measurements were made on each sample for the determination of the R_z parameter. A guide was used to ensure that the same five points on the surface of the samples were measured at each abrasion cycle (25 revolutions).

Regression equations were used to determine the trend of each property. The corresponding R^2 values were also evaluated to assess the quality of the fit.

3. RESULTS AND DISCUSSION

The abrasive wear caused on the ceramic tile surfaces using the ISO [4] and UNE [3] methods was compared graphically. For the whole analysis, mass loss is represented by graph (a), gloss is represented by graph (b), and roughness (R_z) is represented by (c). The blue dots show the wear caused by the UNE procedure and the gray dots show the wear caused by the ISO procedure.

The loss of mass from the ceramic surfaces during the abrasion test presented a linear trend. The gloss change on the ceramic surfaces presented an exponential trend but could be fitted by a linear regression. Demarch [9] showed that exponential equations described more accurately the change in gloss after abrasion. Regarding roughness, the Rz parameter showed a linear trend for most of the surfaces, despite great variation.

As observed by Oliveira and Alarcon [10], mass loss is due to material removal from a tile surface due to the action of particles harder than the ceramic material. The particles abrade the surfaces due to normal and tangential forces acting on the surface of the tiles, resulting in scratches, followed by chipping and material removal. This brittle fracture process, commonly observed in most ceramic materials, results in fracture with little or no plastic deformation. Therefore, there is a loss of mass from the surface of the tile, a change in surface topography, represented by the R_z parameter, and, consequently, a change in gloss of the samples. The mass loss of the unglazed decorated porcelain tile surface is shown in Fig.1.

Up to 500 revolutions, the UNE method results in greater loss of mass compared to the ISO method (Fig.1(a)). Regarding gloss, the reduction is greater when using the UNE method (Fig.1(b)). There are no significant differences in roughness when using both methods, but with a little tendency for higher R_z values for the UNE method (Fig.1(c)). The regression equations are shown in Tab.2.

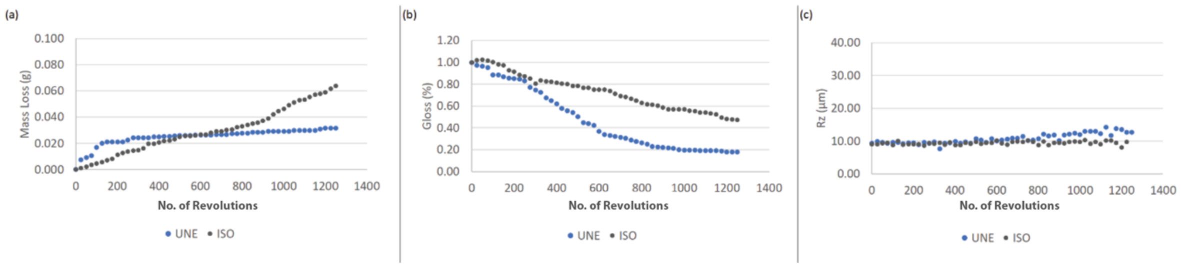

***Figure 1**. Mass loss, gloss and R_z by ISO and UNE methods; unglazed decorated porcelain tile*

Parameter	Standard	Equation	R^2
Mass loss	ISO	y = 0.0000466904x	0.99
	UNE	y = 0.0000333335x	0.88
Gloss	ISO	$y = e^{-0.0005649490x}$	0.99
	UNE	$y = e^{-0.0015293278x}$	0.98
R_z	ISO	y = 0.00045x + 9.15	0.12
	UNE	y = 0.0035x + 8.550	0.78

***Table 2**. Regression equations for mass loss, gloss, and roughness determined by the ISO and UNE methods; unglazed decorated porcelain tile*

The angular coefficient (α) of the equation that describes the mass loss for the ISO method ($\alpha = 4.67\times10^{-5}$) is higher than the UNE method ($\alpha = 3.33\times10^{-5}$). Regarding gloss, the exponent k is considerably higher for the UNE standard ($k = -15.3\times10^{-4}$), and the reduction in gloss is higher for this method. The analysis of the R_z parameter is not feasible, since the R^2 value for the regression equation of the ISO standard is quite low.

The abrasive wear on the surface of the unglazed natural porcelain tile, according to the methods of the ISO and UNE standards, is shown in Fig.2. The behavior is similar to that of the unglazed decorated porcelain tile. The regression equations are shown in Tab.3.

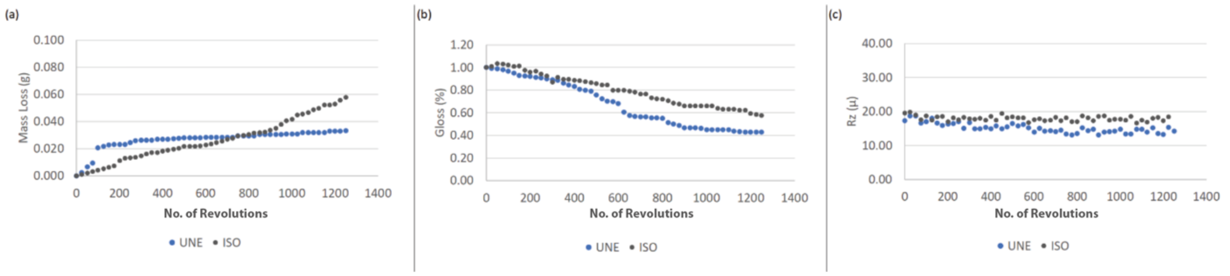

***Figure 2**. Mass loss, gloss and R_z by ISO and UNE methods; unglazed natural porcelain tile*

Parameter	Standard	Equation	R^2
Mass loss	ISO	y = 0.0000420900x	0.99
	UNE	y = 0.0000354870x	0.87
Gloss	ISO	$y = e^{-0.0004083321x}$	0.99
	UNE	$y = e^{-0.0007344942x}$	0.97
R_z	ISO	y = -0.0006x + 18.37	0.11
	UNE	y = -0.0029x + 17.003	0.61

***Table 3.** Regression equations for mass loss, gloss, and roughness determined by the ISO and UNE methods; unglazed natural porcelain tile*

Mass loss is higher for the ISO standard as the angular coefficient of the regression equation ($\alpha = 4.21\times10^{-5}$) is higher than that of the UNE standard ($\alpha = 3.55\times10^{-5}$). However, up to 700 revolutions, mass loss is higher for the UNE standard (Fig.2(a)). The reduction in gloss is higher for the UNE method ($k = -7.33\times10^{-4}$). Regarding roughness, the R^2 values are not significant for analysis.

The mass loss, gloss, and roughness (R_z) caused by the ISO and UNE methods for the unglazed polished porcelain tile is shown in Fig.3. Once more, mass loss is higher when the abrasion test is performed according to the ISO standard. However, up to 300 revolutions mass loss is slightly higher when the test is performed according to the UNE procedure. After that, mass loss is higher for the ISO method ($\alpha = 4.70\times10^{-5}$)(Tab.4).

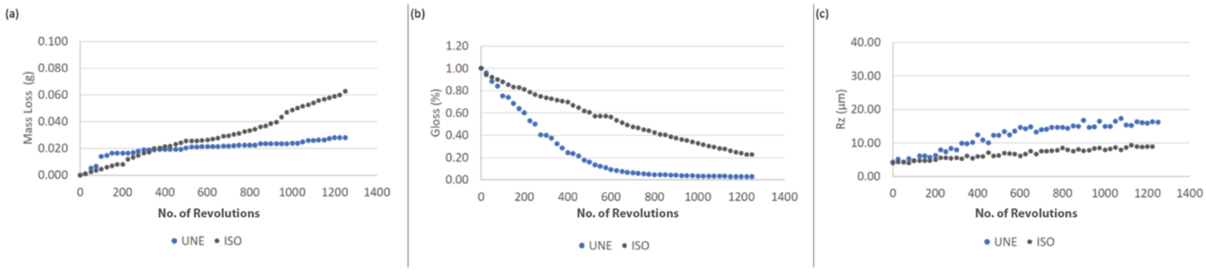

Figure 3. *Mass loss, gloss and R_z by ISO and UNE methods; unglazed polished porcelain tile*

The reduction in gloss is higher when the product is tested according to the UNE method. The "k" value for the UNE method is three times higher when compared to the ISO method ($k = -3.33\times10^{-3}$ for the UNE method, Tab.4). The reduction is gloss is more intense for this finish, an unglazed and polished surface. Regarding roughness, the R_z parameter is higher when the abrasion test is performed according to the UNE method ($\alpha = 1.01\times10^{-2}$)(Tab.4), but the model is not adequate ($R^2 = 0.87$). The R_z values are higher for this finish, a polished surface.

Parameter	Standard	Equation	R^2
Mass loss	ISO	$y = 0.0000470456x$	0.99
	UNE	$y = 0.0000276052x$	0.91
Gloss	ISO	$y = e^{-0.0011104690x}$	0.99
	UNE	$y = e^{-0.0033253055x}$	0.99
R_z	ISO	$y = 0.0041x + 4.27$	0.94
	UNE	$y = 0.0101x + 5.790$	0.87

Table 4*. Regression equations for mass loss, gloss, and roughness determined by the ISO and UNE methods; unglazed polished porcelain tile*

Mass loss, gloss, and roughness (R_z) for the glazed polished porcelain tile is shown in Fig.4. For this finish, the mass loss for both methods is equivalent ($\alpha = 2.96\times10^{-5}$ for the ISO method and $\alpha = 2.93\times10^{-5}$ for the UNE method, Tab.5).

Up to ~700 revolutions the mass loss is higher for the UNE method. However, the fit of the mass loss equation is smaller for the UNE method ($R^2 = 0.89$).

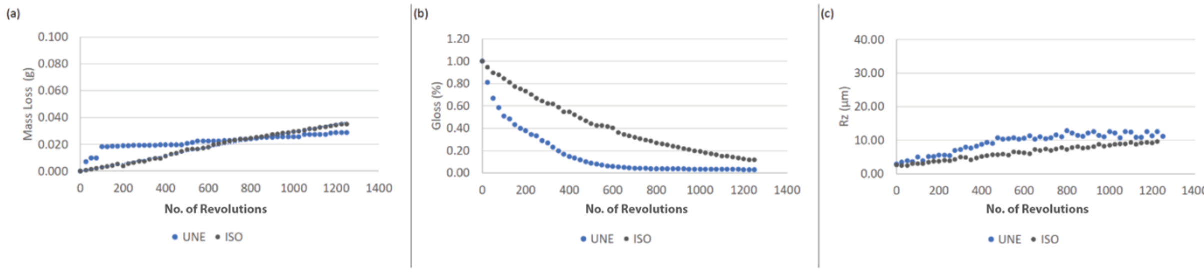

Figure 4. *Mass loss, gloss and R_z by ISO and UNE methods; glazed polished porcelain tile*

The reduction in gloss is higher for the UNE method ($k = -3.56\times10^{-3}$, Tab.5). The reduction is gloss is similar to that of the unglazed polished surface. The R_z parameter is higher for the UNE method ($\alpha = 7.10\times10^{-3}$, Tab.5).

Parameter	Standard	Equation	R^2
Mass loss	ISO	$y = 0.0000295741x$	1.00
	UNE	$y = 0.0000292943x$	0.89
Gloss	ISO	$y = e^{-0.0016604596x}$	1.00
	UNE	$y = e^{-0.0035606291x}$	0.97
R_z	ISO	$y = 0.0059x + 2.67$	0.98
	UNE	$y = 0.0071x + 4.957$	0.79

Table 5. *Regression equations for mass loss, gloss, and roughness determined by the ISO and UNE methods; glazed polished porcelain tile*

Mass loss, gloss, and roughness (R_z) for the glazed glossy tile is shown in Fig.5. The mass loss for this finish is equivalent for both methods ($\alpha = 4.97\times10^{-5}$ for the ISO method and $\alpha = 4.13\times10^{-5}$ for the UNE method, Tab.6). Up to ~800 revolutions, mass loss is higher for the UNE method ($R^2 = 0.85$). Once more, the reduction in gloss is higher for the UNE method ($k = -2.02\times10^{-3}$, Tab.6). The R_z parameter (angular coefficient of the R_z equation) is higher for the UNE method ($\alpha = 10.1\times10^{-3}$, Tab.6).

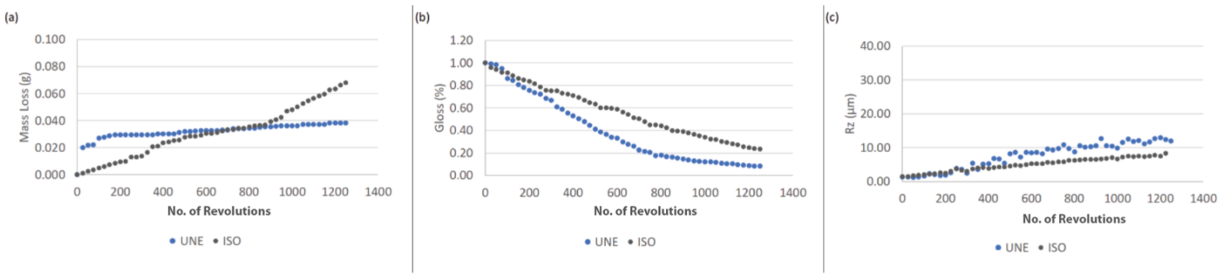

Figure 5. *Mass loss, gloss and R_z by ISO and UNE methods; glazed glossy tile*

Parameter	Standard	Equation	R^2
Mass loss	ISO	y = 0.0000496738x	0.99
	UNE	y = 0.0000413484x	0.85
Gloss	ISO	$y = e^{-0.0010680631x}$	0.99
	UNE	$y = e^{-0.0020196782x}$	0.99
R_z	ISO	y = 0.0053x + 1.76	0.98
	UNE	y = 0.0101x + 1.315	0.93

Table 6. *Regression equations for mass loss, gloss, and roughness determined by the ISO and UNE methods; glazed glossy tile*

Mass loss, gloss, and roughness (R_z) for the glazed satin porcelain tile is shown in Fig.6. The mass loss for this finish is equivalent for both methods ($\alpha = 2.92\times10^{-5}$ for the ISO method and $\alpha = 2.64\times10^{-5}$ for the UNE method, Tab.7). Up to ~650 revolutions, mass loss is higher for the UNE method ($R^2 = 0.86$). The reduction in gloss is higher for the UNE method ($k = -1.17\times10^{-3}$, Tab.7). The R_z parameter is higher for the UNE method ($\alpha = 5.5\times10^{-3}$, Tab.7). Although the surface is satin, its behavior is like that of other polished and glossy surfaces but showing a less intense mass loss and reduction in gloss.

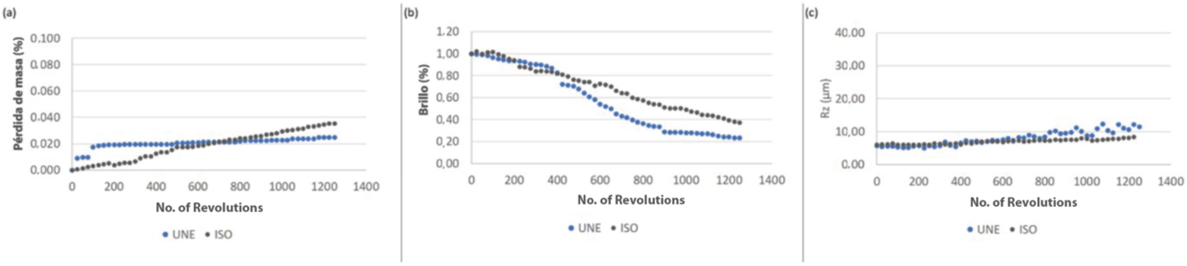

Figure 6. *Mass loss, gloss and R_z by ISO and UNE methods; glazed satin porcelain tile*

Parameter	Standard	Equation	R^2
Mass loss	ISO	y = 0.0000292407x	1.00
	UNE	y = 0.0000263768x	0.86
Gloss	ISO	$y = e^{-0.0007055935x}$	0.99
	UNE	$y = e^{-0.0011676372x}$	0.95
R_z	ISO	y = 0.0018x + 5.91	0.91
	UNE	y = 0.0055x + 4.535	0.90

Table 7. *Regression equations for mass loss, gloss, and roughness determined by the ISO and UNE methods; glazed satin porcelain tile*

Three products intended for use in external areas were tested. They were designed to have higher roughness in comparison to the other surfaces in order to increase their slip resistance.

The mass loss, gloss, and roughness (R_z) for the glazed porcelain tile covered with corundum is shown in Fig.7. Like the other surfaces, the mass loss for this finish is equivalent for both methods (α = 2.75×10^{-5} for the ISO method and α = 2.59×10^{-5} for the UNE method, Tab.8). Up to ~800 revolutions, mass loss is higher for the UNE method (R^2 = 0.86). The reduction in gloss is similar for both methods (k = -3.20×10^{-4} for the ISO method and k = 2.91×10^{-4} for the UNE method, Tab.8). The R_z parameter cannot be analyzed due to the low R^2 value.

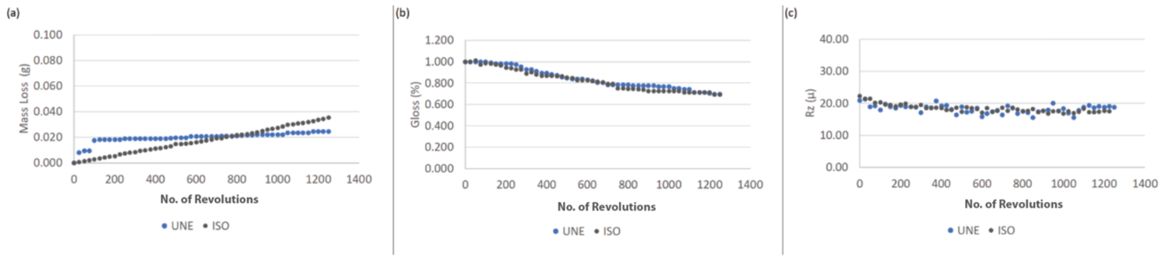

Figure 7. *Mass loss, gloss and R_z by ISO and UNE methods; glazed porcelain tile covered with corundum*

Parameter	Standard	Equation	R^2
Mass loss	ISO	y = 0.0000275373x	1.00
	UNE	y = 0.0000258993x	0.86
Gloss	ISO	$y = e^{-0.0003196667x}$	0.98
	UNE	$y = e^{-0.0002906738x}$	0.97
R_z	ISO	y = -0.0028x + 20.11	0.67
	UNE	y = -0.0011x + 18.992	0.10

Table 8. *Regression equations for mass loss, gloss, and roughness determined by the ISO and UNE methods; glazed porcelain tile covered with corundum*

Mass loss, gloss, and roughness (R_z) for the glazed porcelain tile covered with grits is shown in Fig.8. The mass loss for this finish is slightly higher for the UNE method (α = 3.39×10^{-5}, Tab.9). The mass loss for all revolution intervals is higher for the UNE method (R^2 = 0.86). The reduction in gloss is higher for the UNE method (k = -5.29×10^{-4}, Tab.9). The R_z parameter is higher for the UNE method (α = 9.3×10^{-3}, Tab.9), but the R^2 value is not adequate (R^2 = 0.73).

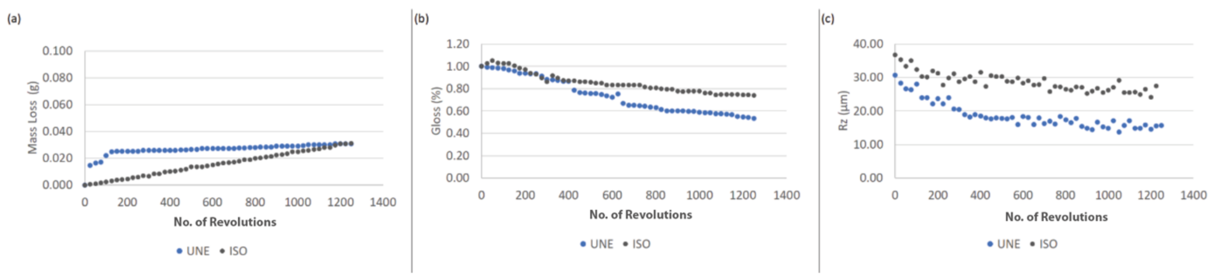

Figure 8. *Mass loss, gloss and R_z by ISO and UNE methods; glazed porcelain tile covered with grits*

Parameter	Standard	Equation	R^2
Mass loss	ISO	$y = 0.0000249943x$	1.00
	UNE	$y = 0.0000338887x$	0.84
Gloss	ISO	$y = e^{-0.0002650938x}$	0.93
	UNE	$y = e^{-0.0005289408x}$	0.97
R_z	ISO	$y = -0.0065x + 32.69$	0.72
	UNE	$y = -0.0093x + 24.521$	0.73

***Table 9**. Regression equations for mass loss, gloss, and roughness determined by the ISO and UNE methods; glazed porcelain tile covered with grits*

Mass loss, gloss, and roughness (R_z) for the embossed glazed porcelain tile is shown in Fig.9. The mass loss for this finish is equivalent for both methods ($\alpha = 3.07\times10^{-5}$ for the ISO method and $\alpha = 2.12\times10^{-5}$ for the UNE method, Tab.10). Up to ~500 revolutions, mass loss is higher for the UNE method ($R^2 = 0.87$). The reduction in gloss is higher for the UNE method ($k = -3.35\times10^{-4}$, Tab.10). The R_z parameter cannot be analyzed due to the low R^2 value.

This product is also coated with a layer containing corundum, which results in a rougher surface. However, the embossed glazed porcelain tile also has a very prominent relief, which tends to influence the wear process. The abrasive agents used in the surface abrasion test do not interact uniformly with the surface due to these specific characteristics.

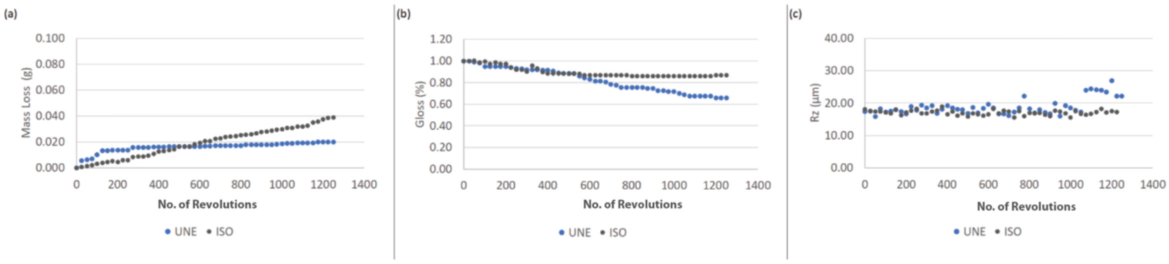

***Figure 9.** Mass loss, gloss and R_z by ISO and UNE methods; embossed glazed porcelain tile*

Parameter	Standard	Equation	R^2
Mass loss	ISO	$y = 0.0000306619x$	1.00
	UNE	$y = 0.0000212126x$	0.87
Gloss	ISO	$y = e^{-0.0001610010x}$	0.74
	UNE	$y = e^{-0.0003354122x}$	0.98
R_z	ISO	$y = -0.00040x + 17.27$	0.03
	UNE	$y = 0.0039x + 16.407$	0.33

***Table 10.** Regression equations for mass loss, gloss, and roughness determined by the ISO and UNE methods; embossed glazed porcelain tile*

In general, the reduction in brightness caused by the UNE method is more intense than that caused by the ISO method. The abrasion resulting from the use of rubber with quartz as an abrasive material is more intense than that caused using corundum + water + spheres, defined by the ISO standard. The ISO standard focuses mainly on the color change of ceramic surfaces due to wear, without considering the reduction in gloss. Therefore, when using the UNE method, which considers gloss reduction, a more complete assessment of the effects of abrasion on ceramic surfaces can be obtained, including both color and gloss change [11].

However, the evaluation of wear should not be limited only to appearance characteristics, as color and gloss, but should also include safety-related considerations, such as slip resistance. Determining this characteristic would require a more extensive wear area. In this study, only the change in surface roughness was evaluated. But the analysis of roughness alone is not capable of providing a complete assessment of slip resistance.

Regarding the R_z values, for covered surfaces (corundum, grit and embossed), designed to provide a high coefficient of friction and, therefore, high slip resistance, no major changes occurred in the conditions (revolution interval) of this study. Probably the tiles kept their slip resistance capacity even after the wear test performed in this study. However, Lot et al. [12] observed that slip resistance was significantly reduced to unsafe levels after the wear test for all surfaces studied.

As a result, it is necessary to perform additional studies in order to quantify slip resistance after the wear test. The wear area defined by the ISO 10545.4 and UNE 138001 methods are quite limited, requiring different approaches to fully assess slip resistance over time.

4. CONCLUSIONS

A study was performed to compare the wear resistance of nine different ceramic surfaces according to the ISO 10545-7 and UNE 138001 methods: Glossy, polished, satin, embossed, covered with corundum and with grits glazed surfaces, and polished, natural, and decorated unglazed surfaces.

As a result, mass loss shows a linear relationship with the number of revolutions for both ISO 10545-7 and UNE 138001 methods. The angular coefficient of the equation for mass loss is greater for the ISO 10545-7 method for almost all surfaces.

The reduction in gloss shows an exponential tendency for both methods. The exponent of the equation for gloss × revolution is two to three times higher for the UNE 138001 method on most surfaces. The reduction in gloss after the UNE method is higher than that caused by the ISO method. Therefore, the abrasion caused by using rubber + quartz in the UNE 138001 method is more intense than that caused by using corundum + steel spheres + water in the ISO standard. In addition, the ISO standard only evaluates color change, while gloss change is neglected.

Regarding roughness, it was not possible to establish a trend for all surfaces due to inadequate R^2 values on rougher surfaces. There is a tendency towards increased roughness on smoother surfaces and decreased roughness on rougher surfaces with both methods.

Additional studies are needed to quantify slip resistance during the wear process. Given the limited size of the wear area in the test methods, alternative approaches may be needed for a comprehensive assessment of slip resistance over time.

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